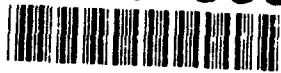AD-A259 966

AFIT/GLM/LSM/92S-18

THE DEVELOPMENT OF AN EXPERT SYSTEM
FOR HAZARDOUS CARGO COMPATIBILITY

THESIS

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AFIT/GLM/LSM/92S-18

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THE DEVELOPMENT OF AN EXPERT SYSTEM

FOR HAZARDOUS CARGO COMPATIBILITY

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Logistics Management

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Captain, USAF   Captain, USAF

September 1992

Preface

The intent of this research was to eliminate some of
the stubby pencil methods found in the daily work of Air
Force transportation personnel through the development of an
automated hazardous cargo compatibility determination
system. We proved that it can be done! Hopefully one day
the LMA at Gunter AFB will realize the true potential of
this product and implement it throughout the Air Force.

Our advisors, Lt Col Richard Moore and Lt Col Dave
Diener always ensured we utilized the correct words and kept
our little fingers off the "Alt-F1" key. Even though we
changed our research topic late in the game, they stuck with
us and provided guidance and assistance which were
instrumental in completing this research.

Our wives, Carol and Jenifer, always understood that we
had a job to do and gave us the room to accomplish it.
Their love, understanding, and above and beyond efforts at
keeping us motivated were a tremendous help.

Our parents also deserve a special thanks for raising
us to be disciplined enough to finish projects which we
start.

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AFIT/GLM/LSM/92S-18

Abstract

This research demonstrates the application of expert system technology to au* mate the aircraft load selection process performed when transporting hazardous cargo. The resulting computer program is an expert system named HAZARD. This system incorporates the regulations governing hazardous cargo compatibility with the heuristics used by experts in loadplanning operations.

The impetus to develop such a system is the January 1993 conversion of regulation guidelines for hazardous cargo classification and management in Air Force Regulation 71-4, to a universal international standard. The Cargo Operations Division of Headquarters Air Mobility Command at Scott AFB, was concerned that this change in procedures and nomenclature may cause confusion to loadplanners. Therefore it is the intention of this research to reduce the impact of this change to regulations through the development of an automated computer product designed for both the experienced and novice loadplanners. The use of this system will improve the accuracy and timeliness of the hazardous cargo compatibility determination process.

THE DEVELOPMENT OF AN EXPERT SYSTEM FOR
HAZARDOUS CARGO COMPATIBILITY TESTING

I. Introduction

General Background

Recent world events, culminating with the collapse of
the Soviet Union, are changing the mission of the United
States Air Force. No longer are forces poised on alert to
counter the Soviet threat. Instead of an environment
characterized by prepositioned assets near a predicted
battle front, the Air Force must now project its power
worldwide through rapid mobilization of forces. To meet the
newly-defined mission requirements, the Air Mobility Command
(AMC) is responsible for transporting entire units anywhere
in the world on short notice. If no constraints existed,
the timely movement of cargo to final destination is, in
itself, not a complex issue. However, realistically, the
mobilization process is constrained by many factors inclu-
ding time limitations, number of aircraft, amount of space
aboard the aircraft, aircraft weight and balance loading
requirements, and finally, rules associated with movement of
hazardous cargo. While, the Air Force currently has the
Computer Aided Loading Manifest (CALM) program to assist
loadplanners in computing weight, balance and proper

placement of pallets for airlift, there is no comparable computer aide to check for compatibility of hazardous cargo. As a result, this critical portion of the loadplanning task must be done manually. A computer program which determines the compatibility of hazardous cargo would accelerate the loadplanning process while ensuring proper and safe loading configuration.

Movement of hazardous cargo, such as flammable liquid, radioactive material and explosives, presents a potential hazard to both personnel and equipment. While the cargo is dangerous in and of itself, specific combinations of hazardous material intensify the danger. For example, ammonia accidentally coming in contact with acid could cause an explosion (Sanborn, 1986:I-4). There are numerous reports of violations in the civilian air cargo industry which resulted in damage to personnel and equipment. To avoid the dangers associated with the accidental combination of hazardous materials, detailed, and often complex, instructions have been provided by regulatory agencies. The potential for error is heightened when an inexperienced loadplanner configures cargo for shipment.

New hazardous cargo compatibility regulations, which incorporate international standards become effective for the commercial industry and the Department of Defense on January 1, 1993. While these new standards are being incorporated into the revision of AFR 71-4, Preparation of Hazardous

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Materials for Military Air Shipment, currently there are no efforts within the Air Force to automate these new rules or to train personnel other than on the job training (Warnecke, 1992).

The incorporation of international standards will change AFR 71-4 from a twenty-nine category system of hazardous materials designed exclusively by and for the United States Air Force, to a nine category, multiple sub-category pattern. These new guidelines include two tables which provide compatibility rules. Exceptions to the rules are identified with multiple notes. While the compatibility determination of two items is a simple task, it becomes increasingly complex when considering multiple pallets, multiple aircraft, and various destinations. For example, determining whether or not spontaneous combustible (Class 4.2) items may be shipped with poison liquid (Class 6.1), is a simple pairwise comparison using the rules of AFR 71-4 (Table 1). The rule is obtained at the intersection of the two classes of the items offered for shipment. In this example, the items are not compatible as indicated by the "X".

However, if additional items are to be shipped such as flammable liquids (Class 3.0) and flammable solids (Class 4.1), the complexity of the problem increases. Six pairwise comparisons are needed to determine the compatibility of the load (Table 2). Each item must be compared against the

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TABLE 1

SIMPLE PAIRWISE COMPARISON OF 2 CLASSES

Class	1.1	1.2	1.3	.	.	.	4.2	5	6.1
1.1									|
1.2									|
1.3									|
.									|
.									|
.									|
4.2	--								X
5									
6.1									

TABLE 2

PAIRWISE COMPARISON OF 4 CLASSES

Class	1.1	.	.	.	3.0	4.1	4.2	5	6.1
1.1					|	|	|		|
.					|	|	|		|
.					|	|	|		|
.					|	|	|		|
3.0	-------------------					O	O	--	X
4.1	-----------------				O	---		--	X
4.2	-----------------				O		-------		X
5.0					|	|	|		
6.1	---------------				X	X	X		

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other three to determine compatibility. In this example
there are both compatible and incompatible items indicated
by the presence and absence of a letter respectively. Some
items can be loaded on the same aircraft with certain
restrictions indicated by the "O". The increased complexity
of manually comparing a large number of items increases the
potential for error and the time necessary to perform the
function.

A typical situation where an automated cargo compat-
ibility checker could have been a significant asset was a
local mobility exercise, Coronet Lightning, at Langley AFB,
VA. Lt Col Worthy Briscoe, the transportation squadron
commander, was involved in a situation where the prepared
aircraft loadplans relied on pre-approved waivers from
HQ/AMC for the Explosive Ordinance Division (EOD) items to
move with other cargo even though they were incompatible.
The pre-approved waivers had expired, and without them, the
existing loadplans in the Mobility Control Unit were in
violation of AFR 71-4. The loadplanners were faced with the
task of reorganizing the contents of ten aircraft to account
for priorities and compatibilities of the hazardous items.
The untimely occurrence required many personnel performing
other functions to stop and help solve the problem. The
solution was developed on paper by drawing matrices con-
taining the hazardous items that required movement. Some
pallets containing multiple hazardous items had to be

separated and shifted to other locations. The process of deriving an acceptable solution lasted thirty minutes at a crucial time where decisions and actions dictated the flow of the mobility (Briscoe, 1992). Had an automated system been available, a solution could have been achieved in less than sixty seconds with a hard copy of the pertinent compatibility matrix and a listing of the hazardous contents within each chalk accompanied by its priority.

Specific Problem

Given the drastic reduction in the Department of Defense budget, and the resulting loss of manpower and experience, it is very probable that personnel with less experience and lower skill levels will be performing the critical function of loadplanning hazardous cargo. In addition, pending changes to AFR 71-4 redefine the rules. These changes negate the advantage of hazardous cargo experience.

Years of training and experience are necessary for a loadplanner to accomplish load configuration accurately and optimally (Sanborn, 1986:II-10). Since air cargo space is at a premium during contingency operations, a computer pro-gram or expert system that incorporates the heuristics of an experienced loadplanner to aid in the decisions involving hazardous cargo compatibility could significantly improve the accuracy, speed, consistency and flexibility of the cargo selection and loading process. This expert system

could be used to help counteract the negative impact of the loss of experience in the work place due to the decreasing manpower and the pending changes to AFR 71-4.

Thesis Objective

This research focuses on the development of a user-friendly expert system which identifies and combines the rules for hazardous cargo compatibility with the heuristics of an experienced loadplanner. This thesis develops, programs, and documents an expert system based on the rules associated with loadplanning hazardous cargo. This system is designed to assist military transportation personnel in the loadplanning function by reconciling all hazardous cargo placement decisions. The expert system software developed for this thesis, HAZARD, has the following features:

1. Stand-alone software for use on any DOS-based microcomputer.

2. Rapid retrieval of cargo compatibility information and related notes to the combinations.

In addition to the expert system, this thesis accomplishes the following:

1. Provides a summary of hazardous cargo compatibility issues and expert systems through a comprehensive literature review.

2. Evaluates existing computer-aided loading systems and their ability to resolve hazardous cargo compatibility issues.

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Investigative Questions

The following questions are investigated to support the objectives of this thesis:

1. Would an expert system significantly enhance the productivity and reliability of aircraft loadplanners in preparing shipments involving hazardous cargo?

2. What rules and heuristics do aircraft loadplanners use when determining compatibility and priority groupings of hazardous cargo?

3. Can these heuristics be programmed into a user-friendly expert system?

4. What procedures are in place to implement newly developed transportation software for Air Force use?

Thesis Structure

This chapter identified the purpose and general direction of the thesis. The literature review, Chapter II, introduces expert systems and reviews the issues involving hazardous cargo compatibility movement. Chapter III identifies the methodology used in selecting an expert system shell and the methodology used in validating and verifying the developed system. Chapter IV contains the research results. Chapter V provides a discussion of conclusions and recommendations. Appendices contain a definition of terms, a user's manual and the program code.

II Literature Review

Overview

Given the dual nature of this thesis, expert systems and hazardous cargo, the literature review addresses each topic individually. Therefore, this chapter begins by introducing expert systems, and then analyzes problems associated with the transportation of hazardous cargo.

Expert Systems

Expert systems are software programs that solve problems by mimicking the thought process by which human beings solve problems (Allen, 1986:6). An expert system solves problems within a given knowledge domain using symbolic logic, derived from an expert, as opposed to mathematical logic. Use of symbolic logic makes it possible to use common nouns such as *eggs, cheese,* or *milk* within the programming code (Giarratano and Riley, 1989:40). By using symbolic logic, the computer is capable of associating relationships between words and responding and providing insight to situations as the expert would.

An expert system is divided into three distinct parts: knowledge base, inference engine, and user interface (Pigford and Baur, 1990:20). The inference engine and user interface are often combined into a computer program called an expert system shell. This shell provides the structure and computer commands which enable the knowledge engineer,

or programmer, to develop the knowledge base used by the expert system. The knowledge engineer is the key element in the development of an expert system since the fundamental task is to gather the expertise, or knowledge, from the domain expert and translate this knowledge into rules. The interaction between domain expert and knowledge engineer is diagrammed in Figure 1.
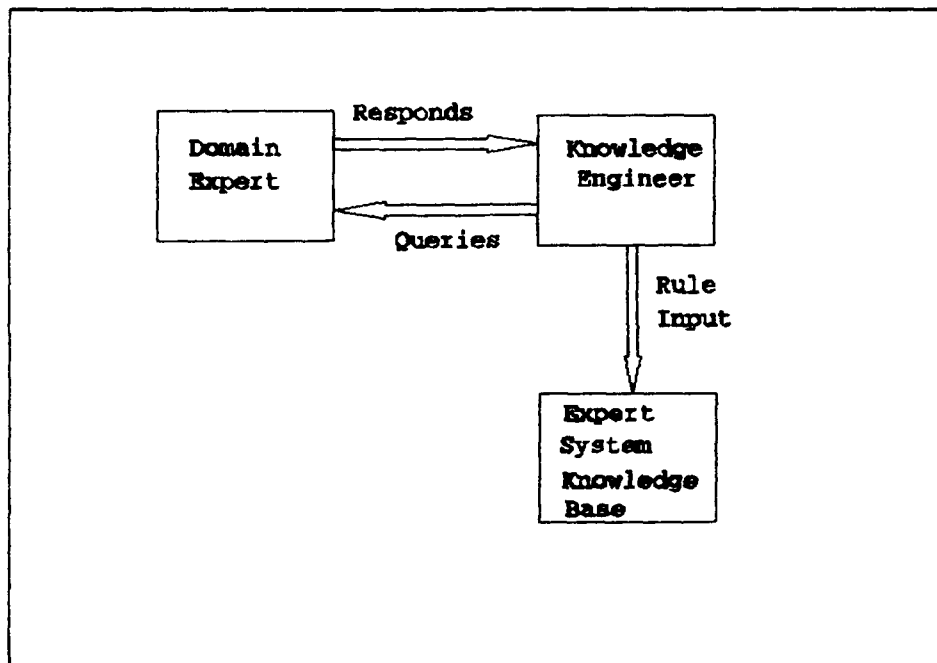
Figure 1. Knowledge Acquisition Process (Pigford and Baur, 1990:98)

Components of an Expert System. As illustrated in Figure 2, there are three main components of an expert system: a knowledge base, an inference engine and a user interface.

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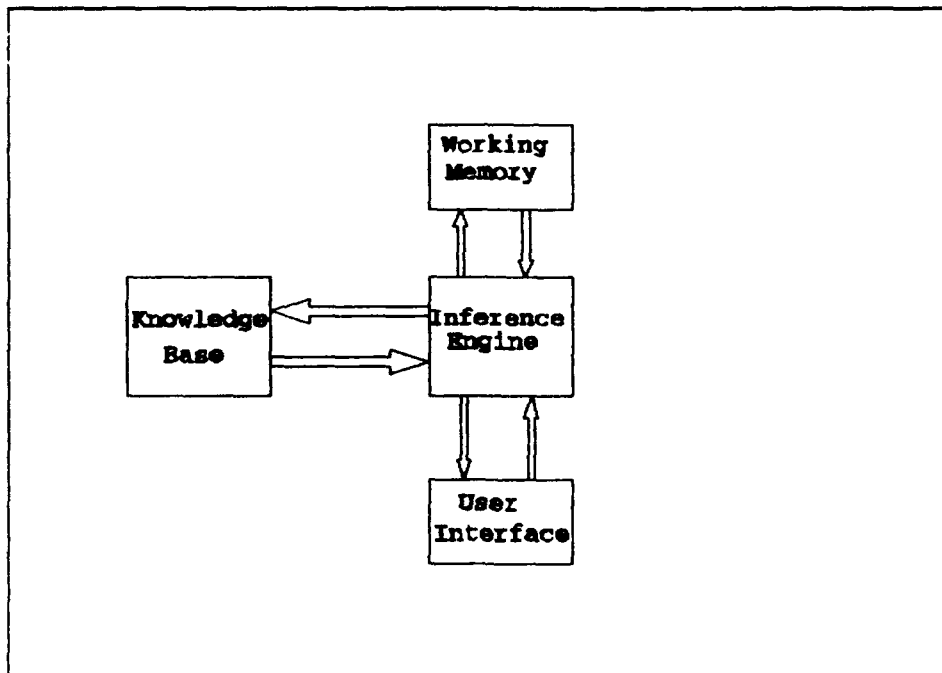
Figure 2.   Components of an Expert System (Luce,
            1992:2)

The knowledge base is a set of rules that represents

the logic behind the formulation of a decision.   A human

expert makes decisions based on experience; the computer's

"experience" is a set of rules or heuristics developed by

the knowledge engineer, an expert system programmer with

skills in knowledge acquisition, and encoded in the

knowledge base.

A knowledge engineer may develop rules in three ways.

Informal rules may be imposed by directors of projects or

programs.   Regulations are formal rules established in

written form.   Lastly, individuals develop their own rules

from experience.   In expert systems, these rules are

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formulated into an if-then format and placed in the knowledge base.

The control section of an expert system is called the inference engine. The inference engine provides the mechanism to establish relationships between the user inputs and the knowledge base. An example of the logic in an inference engine follows:

- John likes all desserts containing chocolate.
- Anne likes all desserts John likes.
- Dessert A is a chocolate covered ice cream sundae.
=> Then Anne likes dessert A. (Borland, 1986:5)

While programming this inference logic into a third generation language such as Pascal or Fortran, requires extensive coding, the same logic in an expert system shell requires only three lines (Borland, 1986:5).

For an expert system to be effective, it is necessary to have a well-designed user interface to allow the user to ask questions, supply the necessary data, and view the results (Luce, 1992:2). Instructions should be clear, responses should be prominent, and a help feature should assist the user at all levels of computer experience. Some common forms of user interface devices include keyboard, mouse, screen, printer, and storage disks.

Logic Structure of Expert Systems. Many computer application programs start by displaying a menu of options, accepting information from the user, processing that information with a sequential set of procedures, then producing a

result (Allen, 1990:27). Most programs have difficulty handling uncertainty or missing data. If any of the information requested from the user is incomplete, the programs are unable to produce an appropriate response.

Depending on the chaining logic employed, an expert system starts by requesting the solution or facts from the user; the expert system processor then reviews preprogrammed knowledge or heuristics to infer new information about that subject. These inferences are derived from rules that an expert would apply to that situation. The new information narrows the scope of the problem by identifying related questions to the user. The expert system makes the associations between facts and continues to query the user until sufficient knowledge is attained to derive a conclusion.

As illustrated in Figures 3 and 4, an expert system uses either backward or forward chaining logic to produce a response. Backward chaining logic starts with the user's goal and searches for rules associated with the goal to reach a conclusion. For example, if you want to determine whether or not it is raining, but you cannot see outside, you examine the environment. If people are rushing indoors, the carpet is wet and thunder is heard, then it can be determined with a certain degree of confidence that it is raining.

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Backward Chaining

Logic Flow

Conclusion

Rule
Rule
Rule
Rule
Rule
Rule
Goal
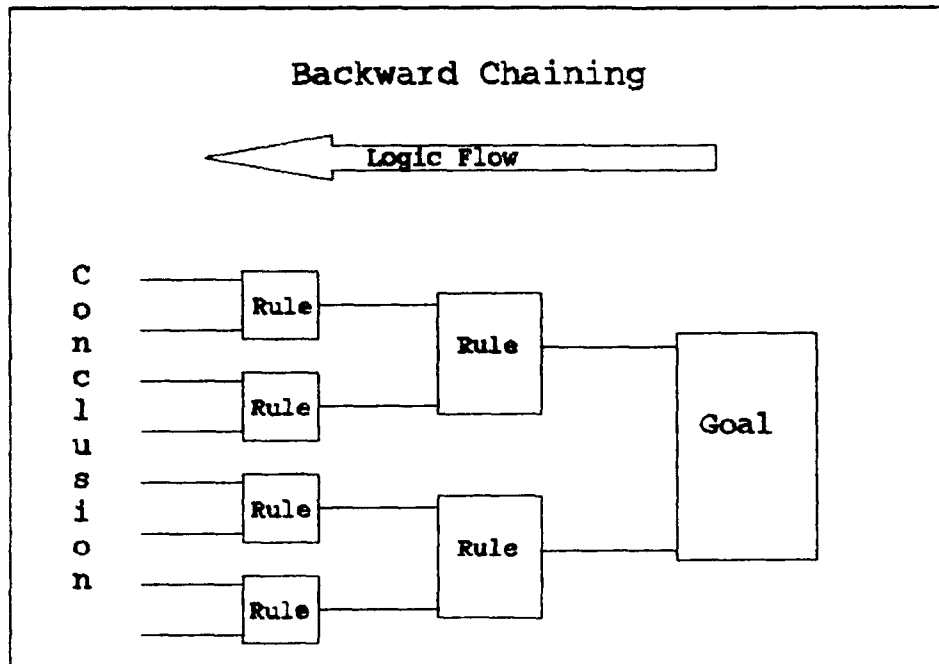
Figure 3.   Backward Chaining Logic

Forward Chaining

Logic Flow

Fact
Fact
Fact
Fact
Fact
Fact
Conclusion
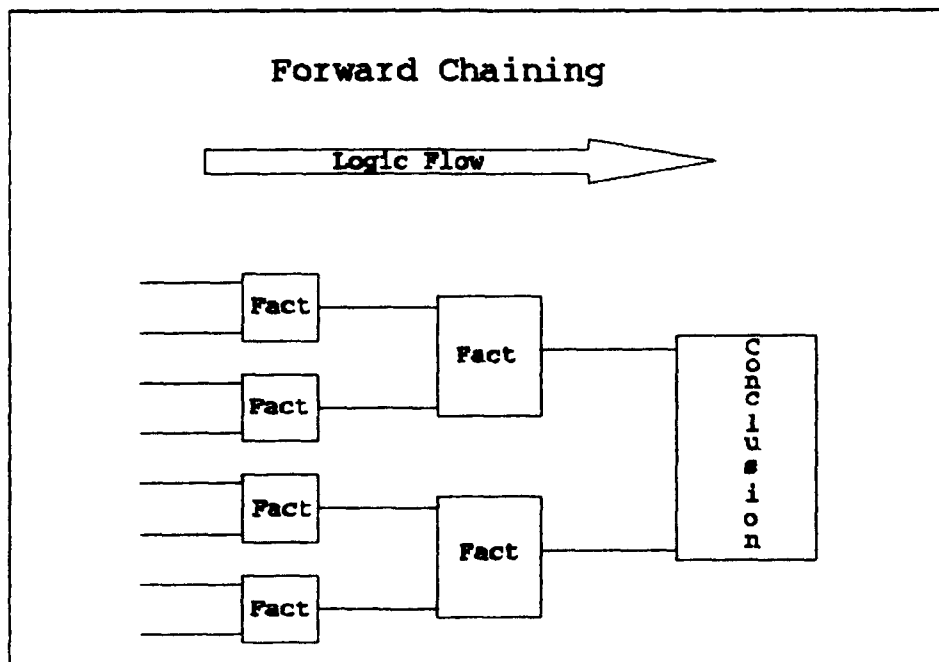
Figure 4.   Forward Chaining Logic

Forward chaining on the other hand, starts with facts and searches for a conclusion based on the facts (Luce, 1992:6). For example, if you see it is raining and you have not left home, then you decide to take an umbrella (Giarratano and Riley, 1989:28).

Process of Developing an Expert System. David Prerau, in an article published in *AI Magazine*, outlines some criteria for selecting the proper areas for using expert systems. Briefly, Prerau states that prior to developing an expert system, the researcher must ensure the rules and heuristics of the problem area can be captured in a programming language. Additionally, Prerau describes desirable features of the developed expert system which include little change to the rules in the knowledge base, ease of user interface, and many experts agreeing on the system's results (Prerau, 1985:27).

The design of an expert system begins with three elements: an expert, a knowledge engineer, and a computer programming language, or more commonly, an expert system shell. The knowledge engineer begins by researching the subject area to develop a basic understanding from which to develop initial questions. The knowledge engineer interviews the expert and creates new questions from the growing knowledge. These knowledge elements are categorized and organized logically to be translated into rules. The rules then form the foundation of the knowledge base and the first

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version of the expert system is presented to the expert as a prototype for validation. This validation is the most crucial stage in developing an accurate and useful system. The modification and verification process with the expert continues until the system performs as originally designated (Pigford and Baur, 1989:99). Once the system responds to situations as the expert would, the system is ready to be used.

Advantages of an Expert System. An expert system has many advantages over a standard computer program. The following list identifies five of these advantages:

1. Speed: an expert system asks only the questions necessary to identify a solution.

2. Explanation: users often need to understand how decisions are achieved, particularly if they place their reputation or life in the hands of a computer supported decision. An expert system is uniquely capable of retracing the logic that leads to a conclusion.

3. Imperfect Information: an expert system can derive a solution, even if not all information is available or when there is a degree of uncertainty. Expert systems accomplish this by providing the user the option to enter a degree of certainty with an input. The solution incorporates the facts and the certainties by using a certainty heuristic threshold. This feature could be used to determine the risks for a bank to provide a loan to a new client. The banker can enter a subjective factor such as client trust. The question could read, "Do you trust the client?" and associated with it is a degree of certainty from 1 to 100 percent. This could be used as one of many factors that may lead to the decision. The solution certainty heuristic could be set to decide to accept the client if the product of the certainties is above a specified level.

4. Symbolic Manipulation: an expert system doesn't have to model reality in quantified terms. Expert

systems can utilize symbolic factors as elements of a problem.

5. Adaptive Learning: some expert systems have the capability to learn from new knowledge and scenarios. (Holt, 1992)

Traditional computer-based decision support systems (DSS) respond to user inquiries by narrowing information in a database down to a specific subject. One problem with information in this decade is that decision factors change more rapidly then ever before (Knowledge Base Systems, 1990:29). The result is that decision logic within a DSS has a short life-span. Some people believe that expert systems have evolved in the past twenty years to become "a workhorse of the industry [for decision support]" (Norville, 1989:24).

Expert System Automation. Time is always a limitation for a manager. As management information systems improve, the volume of data increases and can become unmanageable. Managers routinely receive reports from information repor- ting systems which present hundreds of pages of sorted data. Many hours would be required to review these reports and identify exceptions that require attention. To speed the review process, managers develop rules subconsciously. To the degree an expert system can capture those rules and automate the report review, the exception report can then be the focus of a manager's attention (Holt, 1992). By embedding the processing capabilities of expert system shell software into traditional database management systems

(DBMS), organizations can save the time and money spent extracting the necessary knowledge from expert personnel (Rappaport, 1990:44).

No matter how sophisticated, no single computer application program can perform optimally for all situations. The ideal expert system application involves a problem solving situation requiring repeated use of a complex set of facts and rules in a specific field of knowledge (Allen, 1990:45).

Expert systems used as a decision support system (DSS) have been demonstrated to improve logistics effectiveness and efficiency in corporate and government offices; these successes elevate the need to integrate expert systems technology into logistics curriculums (Cook, 1989:68). Edward Feigenbaum claims in his book *The Rise of the Expert Company* that the application of expert systems often produces a return on investment of over 1000% and speeds up knowledge work by at least a factor of ten (Feigenbaum, 1988:xiii). In today's transient society, the rapid turnover of personnel frequently results in a loss of experience. Carefully developed and well maintained expert systems can provide the continuity and management consistency necessary to handle these fluctuations.

Although expert system applications can be applied to all areas of logistics, the most significant benefit is in decision support (Parker, 1989:432). Traditional software

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takes a long time to develop, and once developed, it can be difficult to maintain. Expert systems are superior because they provide the capability to provide semi-structured and unstructured decisions, flexibility in programming, and ease of learning and use (Allen, 1990:29).

Flexibility in an expert system is provided through the use of modular blocks. These blocks are distinctly separate sections of computer code that aid the programmer or software maintainer to quickly find the specific code location that may require modification. In expert systems, all the heuristics or rules are defined in a specific rules block. These rules can be located, changed, appended, or deleted as needed with minimal knowledge of knowledge-based programming.

A well-written computer program, either traditional application or expert system, should be easy to learn and use. A popular construct today in expert system programming is the incorporation of hypertext. Hypertext is a computer technology which allows a user to receive more information about a subject through the use of context sensitive areas on the computer screen. By highlighting these areas with a mouse, further information on that subject is available. Hypertext enables a user to jump from a given document to related subjects without losing the original text. This feature is more common in expert system shells than in traditional third generation languages (Shim, 1992:36).

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Management Applications. Managers do not always have full knowledge of a situation. Therefore, the capability "to automate more strategic, less structured systems applications, such as complex decision making and knowledge-intensive management level operations that require judgment, knowledge base technology is needed" (Knowledge Base Systems, 1990:29).

No single computer system can satisfy all the information and decision support needs of management. A hybrid system combining traditional programming, fourth generation programming such as computer-aided software engineering (CASE) for using mathematical information, and expert systems for qualitative information would provide the best mix to satisfy all the needs of a user (Gordon, 1989:26). Of all the components of a hybrid system, expert system hold the most promise. In fact, "expert systems have, arguably, pervaded the work place of the world faster than any new technology in history" (Heilmeier, 1988:43). Heilmeier further explains that expert system and DSS app-lications will co-exist to provide support in an increas-ingly complex world of options and solutions (Heilmeier, 1988:43). Expert systems offer several advantages versus the expert: constant availability, perfect recall, knowledge sharing, shorter decision time, and impartiality (Shim, 1988:13).

Successful Expert Systems In Logistics. There have been several successful applications of expert systems to transportation related problems. Examples include: analyzing the work progression of vehicles in a maintenance facility; establishing the routing design and schedule to minimize travel time and fuel costs while maximizing cargo space utilization; training new drivers by evaluating their knowledge and identifying subject areas that require further study (Allen, 1990:67). Specific examples of transportation expert systems are: EXLOAD, GADS and MATHES.

EXLOAD. This expert system was developed by Prabir Bagchi and Barin Nag as a PC-based vehicle dispatch scheduling aid, developed in an expert system shell called VP Expert. This program incorporates the traditional space and time considerations of transportation scheduling with cargo consolidation, vehicle capacity, backhaul considerations, carrier contract regulations, and speed (Bagchi and Nag, 1990:152). These problems are often impossible to solve using standard programming and mathematical optimization techniques due to the difficulty in programming symbolic or non-quantifiable scheduling factors in third generation languages. Many years of scheduling experience are necessary to incorporate all the pertinent factors to perform the dispatch function efficiently and optimally. EXLOAD permits a less experienced scheduler to develop

routing solutions quickly and consistently (Bagchi and Nag, 1990:145).

GADS. This expert system was developed by United Airlines to help airport ramp controllers manage the complex aircraft gate parking problem. Previous to this system, the management was performed by magnetic symbols on wall-sized scheduling boards. Similar to the previous truck scheduling system, GADS was able to eliminate human scheduling errors (Shifren, 1988:148).

MATHES. The Material Handling Equipment (MHE) Selection program is an expert system that selects the necessary type of MHE to move a particular item in a warehouse or factory. Experts in the material handling field used their experience to develop heuristics for this expert system. The system considers the path, distance, weight, size, volume, fragility, and interface to determine the most efficient and appropriate machine to use (Fisher and others, 1988:301). A potential future application of MATHES would be the automatic selection of MHE in a lights-off, automated factory.

Expert System Limitations. Given the current level of development of expert systems, it is unlikely they will replace experts within the next few years. It is not possible to communicate, interpret, learn, document, and model everything an expert knows (Holt, 1992). There are many obstacles in the process of documenting the expertise of an

expert. These obstacles limit the amount of original exper-
tise which is transferred to the product. These limitations
are a result of:

- the knowledge engineer's interpreting skills
- the expert's ability to articulate
- the knowledge a knowledge engineer can capture
- the expert system shell's ability to model and
  manipulate that knowledge. (Holt, 1992)

The reason for elaborating on these expert system
limitations is to show that experts do not have to fear that
a computer will replace the expert unless they are doing a
simple repetitive job that a manager should not be doing in
the first place.

An expert system is unable to think, apply common
sense, or incorporate unique aspects of a new situation. A
critical field such as surgery is one example of something
that is unlikely to be replaced by a computer application;
however, expert systems could be used to perform limited
services within a field, such as Exposure Advisor which
diagnoses diseases for the U.S. Army. Exposure Advisor aids
a doctor by narrowing the range of potential diseases for a
particular case while serving as a training aid to medical
interns (Norville, 1989:24). While not capable of replacing
the doctor, expert systems can improve the accuracy,
completeness, speed, and consistency of an expert's
decisions.

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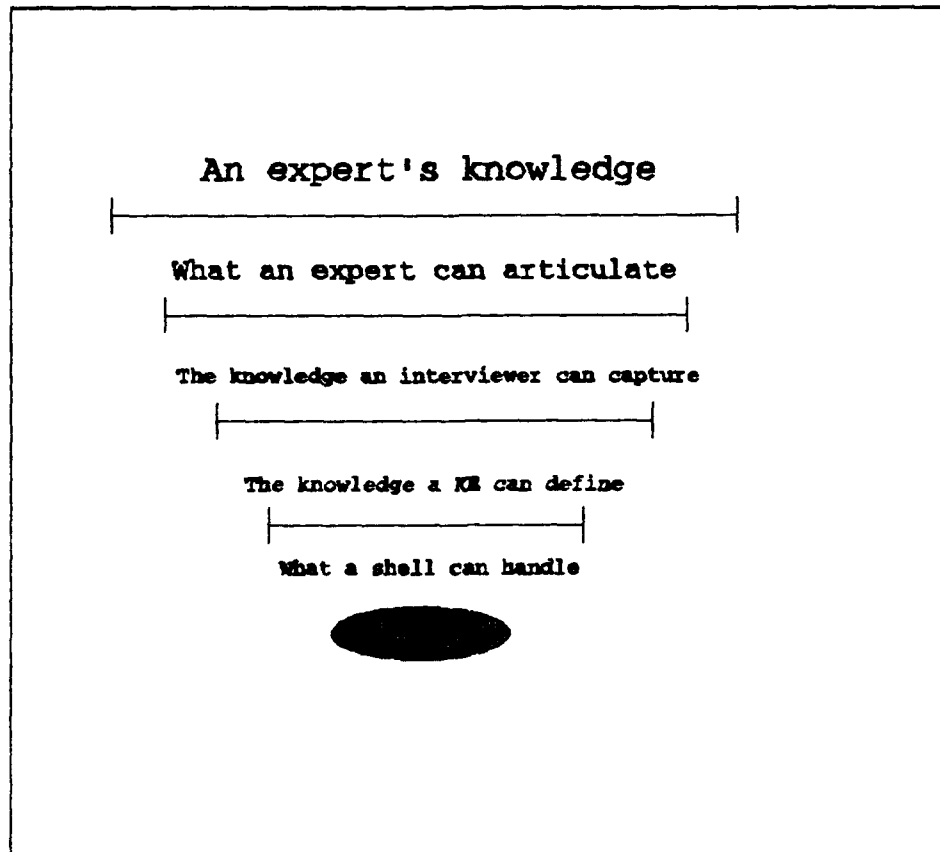
Figure 5. Knowledge Limitation of Expert Systems
(Holt, 1992)

Expert System Summary

This section of the literature review introduced the concept of expert systems. The three main parts of expert system development were explained. Further discussion revolved around how managers could use expert systems as decision support systems, with examples of expert systems used in logistics. Definitions which may enhance the understanding of specific concepts within the realm of expert systems is provided in Appendix A. This chapter will

now survey the process of loadplanning aircraft and the dangers involved in moving hazardous materials.

Process of Loadplanning

The loadplanner begins the loadplanning process by selecting the cargo to be loaded that will maximize the aircraft's utilization and minimize the amount of time the cargo waits for transportation (Sanborn, 1986:II-1). During this process, the loadplanner must determine compatibility of any hazardous cargo items. If an item is incompatible with the cargo identified for a certain aircraft flight, or chalk, that cargo must be set aside for another flight. All compatible cargo is then palletized for aircraft loading for each chalk. Should an item be conditionally compatible, the item is required to be separated from other hazardous items by a minimum of 88 inches. Conditionally compatible items are either put on a different pallet, or loose loaded without a pallet. After determining hazardous cargo compatibility, the loadplanner then uses the Computer Aided Loading Manifest System (CALM) to determine where the pallets or loose cargo should be loaded. This process continues until all cargo has been loadplanned, or set aside for another flight.

Information Systems Automation in Air Force Transportation.
The Computer Aided Loading Manifest system (CALM) version 5.2, is being upgraded to check hazardous cargo compatibility. Unfortunately, this update is based on

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the 1988 version of AFR 71-4; by the time the software is scheduled for release the embedded rules will be obsolete. The current version of CALM runs on a personal computer in fixed aerial ports, and may used in deployed locations on laptop computers to aid military personnel in the loading of aircraft. While, the CALM system determines the placement of various pallets on aircraft based on height, weight, and gross compatibility aspects, it fails to consider the new hazardous cargo compatibility rules that become effective January 1, 1993. CALM will advise the user that there is hazardous cargo on a particular pallet, but does not consider this information for developing loading advice.

The Air Force uses a mainframe computer to run the Aerial port Documentation And Manifesting system (ADAM III), the system which manages the flow of cargo through aerial ports. ADAM III does not connect to bases or locations which do not have an aerial port. While ADAM III does a limited form of compatibility checking based on the item group classification, it does not have the capability to further distinguish the item using the associated notes in AFR 71-4. Therefore, ADAM III often provides incorrect output and compatibility must still be checked manually (Sanborn, 1986:I-16). The Cargo Aerial Port System 2 (CAPS2) is currently being developed at HQ AMC as an upgrade to ADAM III yet the method of determining hazardous cargo compatibility is not improved. Like CALM, ADAM III/CAPS2,

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is not configured for the new rules of AFR 71-4. Furthermore, there are no current plans to encode the new AFR 71-4 rules into either CALM or ADAM III/CAPS2.

The development of an expert system to resolve hazardous cargo compatibility issues is consistent with the stated goals outlined in February 1989 by the HQ USAF Director of Transportation.

Goal I: Enhance wartime readiness by integrating systems which support both the wartime requirements and peacetime operations.

Goal II: Update training for transportation personnel by increasing the exposure to a number of formal training courses and by making computerized training more available in unit learning centers.

Goal III: Automate Air Force transportation by emphasizing a paperless transportation environment.

Goal IV: Streamline operations and increase the productivity of transportation resources in light of current manpower reductions and budget cuts. (Department of Transportation, 1989:20)

An expert system for hazardous cargo compatibility supports these goals. An expert system would enhance the ability to prepare cargo for deployment under both normal and contingency operations. Experienced loadplanners could use the system to augment current procedures for training newly assigned personnel. With possible interfacing with ADAM III, there would be a reduction in paperwork. Additionally, the expert system would streamline the time consuming operations involved in the processing of mobility cargo.

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Prior Research of Expert Systems Use in Loadplanning. Prior research in the area of using expert systems to loadplan hazardous cargo was conducted by First Lieutenant Roderick Sanborn in 1986. That research was limited to a subset of the hazardous classification of items contained in AFR 71-4, and as such only a prototype system was developed. In his final conclusion, Lt. Sanborn found an expert system would be practical for assisting the loadplanner. He recommended that an operational expert system to determine hazardous cargo compatibility have the following features:

1. Implement all load/storage groups of AFR 71-4.
2. Implement all cargo notes of AFR 71-4.
3. Implement hold resolution rules for cargo to wait for another mission.
4. Implement resolution rules for loose cargo.
5. Interface with ADAM III for available cargo.
6. Send results back to ADAM III for report generation (Sanborn, 1986:I-10).

The system developed for this thesis will accomplish recommendations 1 and 2, and allow the user to decide on recommendations 3 and 4. The last two recommendations require the system to interface with existing systems and are the responsibility of the Logistics Management Agency (LMA) at Gunter AFB. Specific recommendations related to program interface or integration will be discussed in answering investigative question number four in Chapter 4.

Hazardous Materials

The United Nations Committee of Experts in the Transport of Dangerous Goods classifies hazardous materials

into nine categories such as explosives, flammable liquids or solids, poisons, radioactive, various types of gases, corrosives and miscellaneous items (Greiner, 1988:50). While these materials are hazardous in their own right, combining two non-compatible items could prove to be deadly.

Due to the heightened public awareness of environmental issues and the increased quantities of hazardous materials transported, safety regulations command greater attention today than 20 years ago (Bradley, 1990:66). The pending revision of AFR 71-4 reflects the DoD response to changes occurring in the commercial sector's requirement for tighter control of the transportation of hazardous materials.

Of all the items transported by both commercial and military air transportation, hazardous materials pose a significant threat to public safety. As a result of the inherent dangers involved in transporting hazardous mat- erials, there are a significant number of regulations specifically designed to reduce the risk (Coyle and others, 1991:359). Among these regulations are Title 49 of the Code of Federal Regulations (CFR), International Air Transport Association Regulations, and for the Air Force, AFR 71-4. Not only do these regulations identify which materials are hazardous, but also provide detailed instructions concerning handling and shipping.

According to Title 49 of the Code of Federal Regulations (CFR) a hazardous material is "a substance or

material that may pose an unreasonable risk to health, safety, and property when transported in commerce" (Greiner, 1991:50). Hazardous cargo as defined by AFR 71-4 is a material that is potentially dangerous to the crew, passengers, aircraft, and other cargo.

Safety Implications. Over two billion tons of hazardous cargo are moved annually in the United States through the various modes of transportation (Witt, 1991: 58). Within the air carrier mode, approximately three percent of all cargo shipped is hazardous (Greiner, 1991:50).

Since air transportation introduces additional variables, not found in ground transportation, (e.g. dramatic changes in pressurization) more stringent restrictions apply to the transportation of hazardous materials by air. For instance, some items cannot be transported as air freight because of their instability at high altitudes. Certain items, due to their chemical nature, can be flown on cargo planes only (Clancy, 1989:25).

In 1988, improperly packaged chemicals spilled on an American Airlines flight forcing it to make an emergency landing (Clancy, 1989:26). Three years later, another commercial passenger aircraft had to make a forced landing in Nashville and evacuate 125 people after the airline realized they were carrying hazardous cargo which had been mislabeled and potentially dangerous to the passengers. The

cargo was labeled as laundry equipment, when it was actually sodium hydroxide, a hazardous chemical (Delia-Loyle, 1991:55).

Federal Policy Concerning Hazardous Material Movement. The Secretary of the Department of Transportation is responsible for securing the nation against the risks associated with the transportation of hazardous materials. Federal policy has been established to promote the safe operations of carriers moving hazardous materials. To implement these policies, the Department of Transportation has proposed legislation for hazardous materials movement to include:

    - Establishing areas of hazardous materials
    regulations that are exclusively Federal, such as
    classification standards and hazard warning systems.

    - Extending Federal hazardous materials regulations to
    all intrastate transportation, including specific
    standards for highway routing, with new provisions for
    resolving disputes.

    - Establishing a safety permit program for motor
    carriers transporting extremely toxic, explosive or
    radioactive material (Department of Transportation,
    1990:120).

While the Department of Defense is bound to comply with federal regulations, there are some allowances due to the nature of the military mission. According to Mr. Warnecke at the Air Force Packaging Evaluation Authority (AFPEA) and author of AFR 71-4:

    We (Air Force) derive regulations from 49 CFR, but then
    we adapt them to military requirements. Basically we
    don't follow quantity limitations. We follow most other
    general requirements but cannot ignore the safety

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concerns which the rules were written for. The International Air Transportation Authority (IATA) and 49 CFR severely limit quantities that we cannot adhere to and still meet the military mission. They do not allow shipments of class A explosives for example, we couldn't survive without those. AFR 71-4 follows civilian and commercial documents but adapts those rules to military requirements. AFR 71-4 is the single document for shipping hazardous materials by air, if we ship by surface, we must follow the commercial rules, 49 CFR. (Warnecke, 1992)

Although the result is an increased danger, some rules of hazardous cargo compatibility may be waived by HQ/AMC during tactical operations, but not during exercises. Chapter 3 of AFR 71-4 describes the procedures for movement of hazardous cargo to maximize the use of military airlift and bypass certain non-compatibility restrictions. In all cases, the basic rule is maximum separation of noncompatible items and personnel. Additional one time waivers of AFR 71-4 rules may be obtained from HQ/AMC.

Summary

This literature review examined the expert system technology and hazardous cargo issues necessary for understanding the direction and development of this thesis. This chapter introduced expert systems and their application as a management tool. Discussion continued with loadplanning operations and the dangers involved with moving and storing hazardous items. The literature review concluded with examples of potential equipment damage and personnel injury to underscore the importance of consistent and accurate management of hazardous item compatibility.

These subjects are combined to demonstrate the potential for expert system applications and the need for such an application in the hazardous management field. The combination of topics leads to the objective of this research: to develop an expert system that determines the compatibility of specific hazardous items and recommends how these items should be safely grouped for shipment.

Chapter III explores the various methods of solving the problem identified. It also provides a discussion of the procedures used in development and validation of the expert system associated with this thesis.

III Methodology

Overview

This section describes the research methodology used to identify the flow of activities through which the problem was researched, a solution was developed, and steps were implemented for that solution.

Problem Identification

As organizations mature and technology advances, the opportunities for new solutions to old problems emerge. Major Wasem, HQ/USAF Transportation Plans and Programs Staff, through his experience with previous computer applications for logistics functions, recommended further work be done in automating hazardous cargo compatibility preparation. Within the transportation field in the Department of Defense, the procedures and processes for handling multiple items of hazardous cargo are drastically changing with the revision of AFR 71-4. The change in regulatory guidance coupled with the loss of experienced personnel in hazardous cargo loadplanning have led to the need for an automated system to assist both the novice loadplanner as well as the experienced loadplanner. Current computer technology and availability make development of an expert system to solve this problem a practical possibility. Expert systems have the capability of capturing and recalling the expertise

previously developed only through formal education and experience.

Research

Initial research was conducted to identify the key issues involved in transporting hazardous materials, and to explore the possibility of automation of key decisions related to hazardous material transportation. Mr. Michael Warnecke, of the Air Force Packaging Evaluation Authority (AFPEA) at Wright-Patterson AFB, is responsible for creating hazardous cargo guidance for the United States Air Force and as such, is the author of AFR 71-4. A preliminary interview with Mr. Warnecke provided an overview of hazardous cargo management issues, guiding regulations, and key personnel responsible for hazardous cargo transportation. Research efforts diverged from the preliminary interview into three areas: previous work done in the automation of hazardous cargo compatibility, the needs of personnel who work with loadplanning hazardous items, and the importance of accurate compatibility management.

Development

There are many methods to develop computer software. These methods range from simply writing program code using existing knowledge, to performing a structured, phase-by-phase approach of analysis, development, verification, and implementation. Using the more simple direct-programming

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approach, the problem often becomes too complex to manage. The intricacy of the hazardous cargo compatibility grouping problem and the utilization of an expert system dictated the necessity to develop the software using the phased approach. The phased approach enabled the development to be accomplished, evaluated, and modified one stage at a time (Goodson, 1990:41). Feedback at the end of each stage created the opportunity to add functions which were not previously explored. The following phases identify the stages of development.

Phase I: Define the Problem and Scope the Objective. Before initiating any specific computer programming development, it is necessary to develop an initial understanding of the subject matter and establish preliminary objectives. Without this framework, the knowledge engineering process has no focus. It is necessary to understand the subject before knowing not only what questions to ask, but how to ask them. For a programmer to achieve specific results, it is necessary to learn all possible factors that affect a solution. Throughout all phases of development, it is essential to understand the needs and capabilities of the ultimate user of the system. While it is much easier to write an expert system to be used by an expert, the purpose of an expert system is to create a system which captures the ability of the expert, but is to be used by a novice. Therefore, Phase I is a preparation phase to create the

framework to identify the needs of the user and the capabilities of the expert with the logical flow of common sense.

Phase II: Knowledge Engineering. This is one of the most difficult phases of the expert system development process. Knowledge engineering (KE) involves extracting the pertinent knowledge, procedures, and relationships within the field of specialization from the expert and converting these bits of information into a rule format in which the expert system shell can operate.

KE is accomplished by interviewing the expert, organizing the information into rules and then writing the rules into an expert system shell. The KE process continues by verifying the system's output with the expert to ensure it is operating properly. This iterative process, although slow and tedious, is nonetheless essential for accomplishment. Phase II is the capturing of expertise into a form that is accessible by a novice. The operation of producing such a system is like a sculptor working with clay. It is necessary to tie all the elements together as a synergistic system as an artist places a nose on a face in proportion and relation to an eye and ear. To enable a novice user to perform as an expert, the novice must understand at a minimum the level of information requested by the program. This is an essential consideration when creating the logic of an expert system.

Phase III: Prototype Evaluation and Modification.

Although the temptation exists to complete the program in the knowledge engineering stage, the final form of the program should be honed in Phase III. The objective of Phase II is to demonstrate the functioning of an expert's heuristics, whereas the objective of Phase III is to improve the interface between the user and the captured expertise. This involves minimizing the number of keystrokes necessary to produce results, organizing the screen for readability, improving the directions to ensure understanding, and ensuring the accuracy of output information. Once the program is determined to be accurate through validation and verification, the need to continue working with the expert to capture knowledge is no longer necessary. The focus is shifted to the needs of the user to ensure the final product is functional and practical. Program functionality and practicality is determined by a sampling of end users.

The prototyping process is an interactive development and evaluation of the software. The iterative process of development continues until the features of the software satisfies the initially defined needs of the users.

Program evaluation will be accomplished through the use of a questionnaire. Forty loadplanning and transportation personnel at HQ AMC, HQ AFMC, LMA, SSC and AFIT will receive a copy of the software as well as a questionnaire (Appendix D) for evaluating the software. Their responses will be

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used to determine necessary modifications to the program to ensure it meets the needs of all loadplanning personnel.

Phase IV: Implementation and Support. There are four issues involved with Phase IV: ownership, distribution, training and updating. These four issues require a central point of contact to address questions, collect suggestions, monitor use, ensure standardization and perform software updates. In the Air Force, these issues for Air Force specific software are managed by the Logistics Management Agency (LMA) at Gunter AFB, AL. Without support, software may no longer be useable as situations change. The motivation for this thesis came from changing regulations and modified procedures requiring a manual determination of compatible items. Without future support from the LMA or another owning agency, this software will become obsolete with the first change to the regulations.

Future Ownership of the Software

As discussed in Phase IV, it is necessary to ensure future ownership of this software. Hazardous compatibility checking is necessary in three scenarios: in conjunction with the Computer Aided Load Manifesting System (CALM), with the Aerial port Documentation and Manifesting system (ADAM III), and by itself for non-aircraft related situations where hazardous items are loaded and stored. A logical application of this program is to automatically feed the information from HAZARD directly into the two previously

mentioned systems to prevent redundantly transcribing information. This concept is further explored in Chapter V.

Conclusion

This chapter detailed the phased approach process used to develop the software for this thesis. The results of the this process are discussed in Chapter IV, with recommendations for modifications and future research and development explored in Chapter V.

IV. Results and Findings

Overview

Chapter IV presents the results of the prototyping process for the developed software. The phased approach process detailed in Chapter III is examined concerning the development of the software for this research. The findings to the investigative questions are addressed in the latter portion of this chapter.

Phase I: Define the Problem and Scope the Objective

The researchers were first introduced to the subject of hazardous cargo compatibility at the Basic Transportation Officer's Course at Sheppard AFB, Texas. AFR 71-4 was introduced during the course to explain the issues involved with shipping hazardous cargo. In the process of selecting a thesis topic, Major Wasem, HQ/USAF Transportation Plans and Programs Staff suggested to the researchers that an automated system for determining hazardous cargo compatibility would be beneficial to transportation personnel in the Air Force.

After reviewing several expert system shells, such as KnowledgePro, VPExpert and Turbo Prolog, the researchers chose to use VPExpert primarily for its intuitive structure and user-friendliness. Other criteria used in the comparison were cost, interface ease with other software, quality of on-line programming help, and quality of user interface.

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Accuracy and reliability were determined to be two primary factors in developing this software. Due to the nature of the hazardous cargo, there is no room for error in the decisions recommended by the software.

Phase II: Knowledge Engineering

The knowledge engineering phase of development began with an interview with Mr. Warnecke, the individual responsible for the development of AFR 71-4. During the initial interview, Mr. Warnecke said that the proposed software could be beneficial to transportation personnel by enhancing the efficiency of the loadplanning process. He also stated the proposed software would be an effective training aid. Mr. Warnecke provided recommendations and insight into interpreting hazardous cargo compatibility rules from AFR 71-4. These rules were converted to if-then statements in VPExpert. A prototype program was developed first to accurately solve the compatibility problems. After the initial compatibility rules were found to be accurate, the researchers concentrated on making the software user-friendly. The rules and loading recommendations coded in the software were thoroughly tested by Mr. Warnecke, and Mr. Del Hamilton (HQ AMC/XONC, Chief Cargo Operations), who determined the output of the software to be valid based on the compatibility rules contained in AFR 71-4.

Phase III: Prototype Evaluation and Modification

Evaluation and modification of the software was accomplished at Gunter, Wright-Patterson, and Scott Air Force Bases. Evaluation was accomplished throughout the use of the software by personnel at these bases. Thirty questionnaires were returned, and through these responses, modifications were accomplished by the researchers. For example, personnel at the mobility loadplanning section of Wright-Patterson AFB suggested incorporating rules for the program to automatically generate chalk groupings and provide the flexibility to move items between chalks based on compatibility and priority. Additional recommendations included providing the ability to print the screens in both a column and row comparison matrix and a verbal descriptive list formats. The programmers of CALM at Gunter AFB and ADAM III/CAPS2 at Scott AFB, reviewed HAZARD and responded to the questionnaire. However, they were unable to provide assistance or encouragement for integrating the features of HAZARD into either system, possibly since it is not written in the ADA programming language.

Phase IV: Implementation and Support

In researching the implementation and support issues for the developed software, it was found that two separate agencies within the Air Force are focal points for Air Force Software. The Logistics Management Agency (LMA) at Gunter AFB is responsible for determining if field-developed soft-

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ware should be implemented through an analysis of need for the software. It is important for field programmers to know there exists a software standard which mandates that all new software must be developed in ADA, a third generation computer language. This mandate is enforced at the Standard Systems Center (SSC) at Gunter AFB who is responsible for the development, distribution and maintenance of computer software for Air Force use.

HQ AMC and loadplanners at Wright-Patterson AFB and transportation officers at AFIT determined the program to be valuable and easy to use. The evaluators from the CALM programming office were not as enthusiastic and collectively determined that HAZARD was extremely hard to use, was no use to a loadplanner, and would not be useful as a training aid for new loadplanners. However, of the other groups who evaluated the software, 96 percent concluded it was extremely easy to use, 75 percent determined it would speed up the loadplanning process, and 92 percent found it to be useful as a training aid. This finding identifies a significant difference of perception that may be a symptom of lack of communication between software developers and end users.

In contrast, transportation personnel who reviewed the software were enthusiastic and readily welcomed the automation of a manual task. However, quite the opposite was true of the CALM programming office. In fact, through their

responses to the questionnaire, it appears to the researchers that the CALM programmers may have been biased against the software even prior to running it. For the CALM programmers to determine that HAZARD was "extremely hard to use," while loadplanning personnel with little computer experience determined HAZARD was "extremely easy to use" identifies another problem with communication between the end user and the developers of CALM. Based on the examples just cited, a procedure needs to be established to better improve the communication between the producers of CALM and the ultimate users, the loadplanners. This issue is further discussed in Chapter V.

Answers to Investigative Questions

The four investigative questions posed at the beginning of this research were addressed through the research and development of this thesis.

Investigative Question 1. Would an expert system significantly enhance the productivity and reliability of aircraft loadplanners in preparing shipments involving hazardous cargo?

The results of this research determined that the developed expert system would assist in the efficiency of the loadplanning operation. A majority of software evaluators, composed of transportation personnel and CALM programmers, determined this program will not only save time in performing compatibility checks, but will be a useful

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tool for performing what-if analysis when configuring loads. Additionally, the output of the expert system contains accurate results based on regulation guidelines and exceptions, thereby reducing the likelihood of human error inherent in manually determining hazardous cargo compatibility.

Even though 100 percent of the responses from the personnel who program CALM at the LMA determined that HAZARD would not enhance the loadplanning process, 79 percent of the loadplanners who evaluated the software determined HAZARD would enhance efficiency. However, several load-planning personnel addressed concerns that the developed system could not be run in conjunction with CALM, thereby limiting an increase in efficiency. Presently if the loadplanning operation only has one personal computer, HAZARD would first be run to perform a preliminary compat-ibility and priority analysis, then the loadplanner would run CALM to determine the weight and balance of the air-craft. Even though switching between programs may be a nuisance, it was determined that there would still be a reduction in time versus determining compatibility manually. If HAZARD was developed as a memory resident program, CALM and HAZARD could be run simultaneously.

Investigative Question 2. What rules and heuristics do aircraft loadplanners use when determining compatibility and priority groupings of hazardous cargo?

The rules used by loadplanners to determine hazardous cargo compatibility are contained in AFR 71-4. This regulation incorporates the rules of hazardous cargo compatibility as determined by Title 49 of the Code of Federal Regulations (49CFR), and then tailors these rules to meet the needs of the Air Force. Basically all hazardous items must be compared using all possible pairwise combinations. Compatible groupings are then analyzed to determine which configuration should go first based on priority. This is where the loadplanner's heuristics for priority groupings are taken into account. The heuristics were derived from interviewing loadplanners and analyzing the loadplanning methodology with respect to priority of cargo. The combination of reviewing AFR 71-4 and interviewing loadplanners provided sufficient information from which to develop an expert system capable of imitating the expert's actions.

Investigative Question 3. Can these heuristics be programmed into a user friendly expert system?

Using the expert system shell, VPExpert, to code the if-then rules of AFR 71-4, and Turbo Pascal to provide numerical manipulation for suggesting chalk groupings, it was evident that the rules could be programmed.

Some of the user feedback from the prototype questionnaire classified the software as user-friendly. According to Mr. Del Hamilton, Cargo Operations Specialist at HQ AMC with 22 years experience,

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The program would be very helpful and can be implemented with the change of 71-4. Panic will set in with experienced loadplanners with the new terminology and UN numbers in the revised version of 71-4. A program like this will really help since you don't need to be an expert to use it. (Hamilton, 1992)

While, 73 percent of the program evaluators determined the program to be easy to use, 27 percent found it extremely hard to use. However, if only the loadplanners' responses are evaluated, 96 percent found the program easy to use. Again, this indicates some type of communication gap between the users of transportation software and the CALM programmers.

Investigative Question 4. What procedures are in place to implement newly developed transportation software for Air Force use?

The first step to implementing new software is to obtain a sponsor. This sponsor could be selected from the programmer's Major Command (MAJCOM), who in turn, requests support from the LMA. However, by virtue of the fact that the LMA reports directly to the Air Staff, a more responsive route for gaining support is to request sponsorship directly from the Air Staff. The LMA publishes and distributes a newsletter with all available software for the various logistics fields. Either the LMA or SSC will prototype the software, modify it as needed and implement it as they see fit (Siler, 1992). It is the role of Air Staff to ensure the customer receives adequate software support.

The researchers gained support from the Air Staff who distributed HAZARD to the SSC for evaluation. The SSC has been working on incorporating hazardous cargo compatibility features for the updated version of CALM, therefore, the SSC, at this time, does not have plans to implement HAZARD. As mentioned in Chapter II, this updated version of CALM does not incorporate the new hazardous cargo compatibility rules which go into effect January 1993. Therefore, after evaluating the software, HQ AMC/XONC determined that HAZARD will not only smooth the transition to new international guidelines for hazardous cargo management, but would aid all loadplanners from novice to expert; and as such, they will distribute HAZARD as an approved-for-use program to all AMC cargo operations worldwide.

Conclusion

The development of HAZARD was a formal, four-phase process that successfully produced a complete, accurate, and useful management tool that satisfies the users' needs based on responses to the questionnaires. The stages of development included: problem identification, research, logic and software development, and implementation. The prototyping process was used to test the validity and applicability of HAZARD. The software developed for this research was found to be both accurate and reliable as well as user-friendly. Although the researchers expected more support from the SSC

for future development, the void was filled by HQ AMC who agreed to implement HAZARD in conjunction with the distribution of AFR 71-4 in January 1993. Chapter V further explores the research conclusions and identifies recommendations for further research.

V. Conclusions and Recommendations

Overview

The purpose of this chapter is to provide a summary of the research process and findings, with recommendations for further research. The intent of this study was to develop a user-friendly expert system to determine hazardous cargo compatibility. By answering the investigative questions and developing the software, the researchers' efforts resulted in a computer system called HAZARD which accurately, efficiently, and quickly satisfies the needs of loadplanners to determine compatibility groupings from multiple hazardous items.

Conclusions

The HAZARD system was evaluated by: HQ AMC/LGT, LMA, SSC, HQ AFMC, and AFIT Transportation Officers. The implementation of recommendations from the prototype feedback resulted in the final form of HAZARD which satisfies the initial objective of this research effort, to develop a computer system to automate the compatibility checking requirement for hazardous cargo.

There is an apparent difference in perception concerning the value of HAZARD between the users and the computer programmers who produce CALM and ADAM III. Neither the programmers of ADAM III nor CALM felt their systems required an improved compatibility checking system, even

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though neither system incorporated international standards nor the exceptions to the rules. While CALM and ADAM III are quite capable of performing their primary function, these programs ignore an important dimension of the loadplanner's duties -- determining hazardous cargo compatibility. This oversight forces a loadplanner to manually perform a comparison of hazardous items from the regulations; a process which is tedious, time consuming, and prone to error.

Recommendations

The following four recommendations identify further research that can enhance the existing usefulness of HAZARD and hazardous management issues:

1. The capability within HAZARD to electronically transmit waiver requests for incompatible items to HQ AMC/ LGT, either through a facsimile machine or modem connection. This would eliminate nearly all paperwork related to the redundant transcribing of information contained in HAZARD.

2. Develop a version of HAZARD, for use with CALM or ADAM III/CAPS2, which would remain in the computer's random access memory (RAM) until a hot key sequence is depressed. This would allow quick access to compatibility information currently unavailable with CALM or ADAM III/CAPS2. Load-planning automation should allow a loadplanner to enter the raw data into the computer once, and all pertinent manipu-lations of that data should be accessible from a central

program as mentioned before. Using the present computer windowing and multitasking technologies, HAZARD could be a memory resident routine for utilization from any program as needed without having to exit one and start another. Since no changes would be required of existing systems, the primary advantage to this recommendation is the speed by which it could be implemented throughout the Air Force.

3. Combine existing loadplanning systems, CALM and ADAM III/CAPS2 into one loadplanning program. The Air Force has invested millions of dollars into the development of these two separate, yet similar programs. There are a significant number of overlapping features between the two systems. A combined effort starting from a customer audit could consolidate the work into a central system and eliminate the unnecessary expenditure of resources on duplicate efforts.

4. Conduct a study to determine if the localized communication problems seen between software developers and end-users in this study are indicative of a more widespread problem throughout the Air Force. This study could be accomplished by examining specific software which has been developed and how sufficiently it has met the needs of the users. By identifying, in specific terms, the possible widespread communication gap between computer products that are produced and how sufficiently the actual needs are met, with specific recommendations, significant enhancements

could be forthcoming thereby improving all logistics software by improving the software development process.

5. The introduction of the new international standards will require that every loadplanner be retrained to some extent. If HAZARD is not acceptable to the LMA for some reason, the problem of determining hazardous cargo placement still exists as a manual task and thus, some form of automation is needed which incorporates the new rules of AFR 71-4. While ADAM III and CALM have programming efforts under way to enhance hazardous cargo compatibility determination, these efforts are based on the current rules, and will be obsolete by January 1, 1993. It is appropriate therefore to suspend the development of any programming efforts which include the old rules for hazardous shipment and have a projected release date after January 1, 1993. Consequently, the next logical step would be to incorporate the capability demonstrated by HAZARD into existing Air Force systems to ease the transition to the new standards. Although this recommendation may be more time consuming than recommendation number two, the primary goal of providing accurate and reliable hazardous cargo compatibility data would be accomplished.

Summary

The initial goal of this research was to produce an expert system to assist loadplanners in determining hazardous cargo compatibility in light of forthcoming

regulatory changes. The result of this research effort is in the form of a ready to use software package which will be maintained by the researchers and distributed by HQ AMC in conjunction with the January 1993 revision of AFR 71-4. While the initial goal of this research was achieved, a significant problem was brought to the forefront. There appears to be a conflict between computer automation needs from a user's perspective and the software being developed at the LMA. By using techniques such as total quality management and customer audit surveys, this gap between actual user's needs and the developer's perception of these needs could be diminished.

Appendix A: Definitions

Algorithmic Logic - Formula based logic where meaning is expressed in numerical terms and the order of operations can be predicted in advance. Most conventional computer programs use algorithmic logic (Schoen, 243).

Artificial Intelligence (AI) - A field of study and application concerned with identifying and using tools and techniques that allow machines to exhibit behavior that would be considered intelligent if it were observed in humans (Holsapple, 337).

Backward Chaining - One of several methods used in an inference engine to select and operate on components of a knowledge base. An example of backward chaining can be shown with a series of procedural rules of the form IF x THEN y; where x is a condition and y is a result. When backward chaining is used, the system would start with a possible result, of the form y and look for a rule or combination of rules that has or generates the specific result y (Schoen, 243).

Comment - A portion of a rule consisting of internal documentation about that rule (Holsapple, 338).

Database - The component of an expert system which is used by the inference engine as a "notepad" to hold data, conclusions and intermediate results (Barrett, 238).

Decision Support System (DSS) - Computer programs based on various deterministic or probabilistic optimization methods used in managerial decision making (Schoen, 245).

Domain Expert - An individual with detailed knowledge about a particular area or field (Schoen, 245).

Decision Tree - A way of representing a series of choices, drawn like the branches or a tree (Barrett, 238).

Expert System (ES) - A computer-based system composed of a user interface, an inference engine, and stored expertise in the form of a knowledge base. Its purpose is to offer advice and solutions for problems in a particular problem area. The advice is comparable to that which would be offered by a human expert in that problem area (Holsapple, 339).

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Forward chaining - Also known as data driven reasoning. An
    inferencing strategy whereby the expert system is given
    some data, and uses its rules to work out any new
    implications this might have (Barrett, 239).

Heuristic - A rule of thumb; a piece of practical expertise
    which usually works in practice; a rule of good guessing;
    a piece of compiled hindsight. Expert systems are
    largely made up of heuristics (Barrett, 239).

Inference Chain - The sequence of steps or rule applications
    used by a rule based system to reach a conclusion
    (Goodson, 42).

Inference Engine - That component of a knowledge-based
    system which provides the primary reasoning and control
    strategies used to operate the system (Schoen, 249).

Knowledge Base - The part of an expert system containing
    application specific reasoning knowledge that the
    inference engine uses in the course of reasoning about a
    problem. In expert systems whose reasoning knowledge is
    represented as rules, the knowledge base is a rule set or
    rule base (Holsapple, 340).

Knowledge Based System (KBS) - A computer system in which
    the knowledge used is made explicit, and is separated
    from the computer programs which interpret and apply it.
    Expert systems are a particular type of knowledge based
    system (Barrett, 240).

Prototype - A computer program that has not been completed
    to fully operational status but is sufficiently
    functional that its operation can be demonstrated
    (Schoen, 250).

Rule - A statement of expertise in the form:
        IF these conditions are true
        THEN these conclusions or actions follow (Barrett,
        241).

Shell - A kind of expert system development tool consisting
    of two stand alone pieces of software: a rule set manager
    and an inference engine capable of reasoning with rule
    sets built with the rule set manager (Holsapple, 343).

Validation - The formal process of testing a computer
    program to be sure that it meets the design requirements
    given for its development, usually by test cases or other
    prespecified procedures (Schoen, 252).

Verification - The process of proving that the operation of

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computer program does not generate errors or problems, usually by operating it in an environment similar to that in which it will eventually be used. The performance and results must conform to the expectations of the developer and user (Schoen, 252).

Appendix B: HAZARD Software Code

VPExpert Code

```
!*******Program Haze.kbs By Douglas Furst, Captain,
USAF*************

bkcolor=1;                              ! Blue background
ENDOFF;                                 ! no need to press end
key for input
execute;                                ! return to dos prompt
when done
RUNTIME;                                ! automatically runs
upon starting
ACTIONS
reset ALL                               ! clears variables
receive elements.dat,redo               ! if redo<>yes then
print opening screen
find header                             ! See rule header_screen
delete elements.dat                     ! resets data files
delete elements.tad
delete compat.dat
delete priority.dat
RESET ALL
color=15                                ! fore color white

!********* CONTROL SECTION*******************

cls
display"              //////     Cargo Compatibility
Determination  \\\\\\
"
!***** Send data to external file
reset element
i=1
find element                            ! get first item
whiletrue element<>No_more_items then
 substr @element,expl,0,3               ! save first three
characters in expl
 reset grouper                          ! erase grouper variable
 find grouper                           ! decide if element is <
2.0
 reset priority
 find priority
 ship priority.dat,priority
 ship elements.dat,element              ! save element to
external file
 reset element
 cls
 i=(i+1)
 find element                           ! get next item
```

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```
end
!***** Create a 1x1 cross reference of all items identified
cls
display"                              Please wait, "
clroff
display"           ////////   Cross referencing data input.
\\\\\\\\"
ccall crosref,""                        ! execute external
program crosref
clron
display" "
display"/////  Compatibility rules are being applied to the
                 combinations  \\\\\\"
!***** Get xref data from file and compare
reset all
nitric_flag=yes              ! to ensure message is displayed
once
group1=yes                   ! to ensure message is displayed
once
close elements.tad
receive elements.tad, el     ! get first element from file
find el
whileknown el                ! loop until data is finished
   receive elements.tad, e2  ! get second element from file
   reset c_order
   find c_order
   reset compat
   reset except
   find except
   find compat               ! determine compatibility
   ship compat.dat,compat    ! send compatibility to ext
file
   receive elements.tad, el  ! get next element
end                          !     until data is done
!***** display routine
ccall hazdis.com," "                    ! display output chart
color=15                                ! letter color white
!****** repeat program or exit?
receive elements.dat,again              ! if again=yes, see
whenever repeat
Delete elements.dat
Display"Thank you for using Hazard, safe transporting.
                 (Press any key to exit.)~";


!******* WHENEVER SECTION (forward chaining)**************

WHENEVER REPEAT
     if again=yes then reset ALL
     chain haze;                 ! rerun the program from start
```

```
!******* RULE section (backward chaining)*******************

RULE el_first                    ! patch to fix el not reading
     if el=UNKNOWN then          ! correctly above
     receive elements.tad,temp
     el=(temp);

RULE HEADER_SCREEN
     if redo<>yes then
cls
COLOR=15
Display" Welcome to HAZARD, a hazardous cargo compatibility
determination program based on the AFR 71-4 (Jan 93)
guidelines which follow international rules.

                      An Expert System by:
                 Captain Douglas Furst, USAF
                             and
                 Captain Ronald Smith, USAF

     HAZARD identifies the compatibility of hazardous cargo
items, and provides recommendations for chalk groupings
based on compatibility and priority rules. Compatibility is
determined by the CLASS and/or GROUP of hazardous items.
Incompatible items are not permitted to travel concurrently
by military mode. During contingencies, some restrictions
may be waived by HQ/AMC (See chapter 3 in AFR 71-4).

                      Press any key to begin HAZARD:~"
     header=yes;

RULE explode
     if el<2 and e2<2 then
     substr @el,group1,3,1
     substr @e2,group2,3,1
     asc @group1,agroup1
     asc @group2,agroup2
     find order_g
     reset gcompat
     find gcompat
     reset except
     find except
     compat=(gcompat);

RULE order_group
!    Ensure that group1 < group2 for logic flow
     if agroup1>(agroup2) then
     dummy1=(group1)
     dummy2=(group2)
     group2=z
     group1=(dummy2)
     group2=(dummy1)
```

```
        reset agroup1
        reset agroup2
        order_g=complete;

RULE order_class
!    Ensure that e1 < e2 for logic flow
     IF e1>(e2) then
     dummy1=(e1)
     dummy2=(e2)
!    This prevents e1 from equaling e2 for chaining condition
below
     e2=999
     e1=(dummy2)
     e2=(dummy1)
     C_ORDER=DONE;


!****** Inserting explosive grouping********************

RULE exploder                   ! Inserts group letter after
     if expl<1.5 then           ! explosive class
     group=g
     concat @expl,grou          ! combines letter g to class #
       cls
       find @group              ! finds group for class i.e g1.1
       letter=(@group)
       concat @letter,expl      ! joins group to class i.e.
                                      1.1H

       concat _Explosive,expl   ! completes the name:
                                      1.1H_Explosive

       element=(expl)
       reset expl
       reset @group
       grouper=yes
     else grouper=no;


!**** Non explosive pair Compatibility Rules based on class

RULE one_point_one
     if e1=1.1 and e2>2 then compat=N;

RULE one_point_two
     if e1=1.2 and e2>2 then compat=N;

RULE one_point_three
     if e1=1.3 and e2=2.1 or e2=2.3 or e2=3 or e2>=4.2 and
e2<=6.1 or e2=8 then compat=N;

RULE one_point_four
     if e1=1.4 and e2=2.1 or e2=2.3A or e2=2.3O or e2=3.0 or
e2=4.2 or e2=6.1 or e2=8.0 then compat=C;
```

```
RULE one_point_five
    if e1=1.5D and e2=2.1 or e2=2.3A or e2=2.3O or e2=3.0 or
e2=4.2 or e2=6.1 or e2=8.0 then compat=C;

RULE two_point_one_2.31_a
    if e1=2.1 and e2=2.3A then compat=N;

RULE two_point_one_2.31_other
    if e1=2.1 and e2=2.3O then compat=C;

RULE two_point_one
    if e1=2.1 and e2=4.2 or e2=4.3 or e2=5.1 or e2=5.2 or
e2=6.1 or  e2=7.0 or e2=8.0 then compat=C;

RULE two_point_three_zone_A
    if e1=2.3A and e2=3.0 or e2=4.1 or e2=4.2 or e2=4.3 or
e2=5.1 or  e2=5.2 or e2=8.0 then compat=N;

RULE two_point_three_other_zones
    if e1=2.3O and e2=3.0 or e2=4.1 or e2=4.2 or e2=4.3 or
e2=5.1 or  e2=5.2 or e2=8.0 then compat=C;

RULE three
    if e1=3.0 and e2=4.1 or e2=4.2 or e2=4.3 or e2=5.1 or
e2=5.2 then compat=C;

RULE three_to_five
    if e1>=3.0 and e1<=5.2 and e2=6.1 then compat=N;

RULE eight_1
    if e2=8.0 and e1=4.1 or e1=5.1 or e1=5.2 then compat=C;

RULE eight_2
    if e2=8.0 and e1=4.2 or e1=4.3 or e1=6.1 then compat=N
!All remaining non-explosive cases, elements are compatible
    else compat=Y;

!***** Rules for explosives based on groups*****************

RULE itself
    if group1=@group2 then gcompat=Y;

RULE CDEN
    if group1=C or group1=D or group1=E or group1=N and
    group2=C or group2=D or group2=E or group2=N then
    gcompat=Y;

RULE S
    if group2=S and group1<>L and group1<>A then gcompat=Y

! **** remaining explosives compatibility******************
    else gcompat=N;
```

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```
!****** Notes for classes*******************************

RULE Note_B
     if e1=7.0 or e2=7.0 and fissile_III=yes then except=yes
     compat=N;

RULE Note_C
     if e2=7.0 and e1=1.1 or e1=1.2 or e1=1.5 and
     radio_solid=yes then except=yes compat=Y;

RULE Note_D
     if e1=6.1 and e2=8.0 and cyanides=yes then except=yes
     compat=N;

RULE Note_E
     if e1=8.0 or e2=8.0 and nitric=yes and nitric_flag=yes
     then except=yes nitric_flag=no
color=30
display"      \\\\\\\\\\********* CAUTION ********//////////"
color=15
display"Nitric acid in carboys must be separated by 88
inches or more
   from any other corrosive in a carboys container.
            (press any key to continue)~";

!********* notes for groups********************************

RULE Note_1
     if group1=B and group2=C or group2=D or group2=E and
     UNI=UN0257 then except=yes gcompat=Y;

RULE Note_1.5
     if group1=C or group1=D or group1=E and group2=C or
     group2=D or group2=E and UNI=UN0009 then except=yes
     gcompat=Y;

RULE Note_2
     if group1=B and group2=C or group2=D or group2=E or
     group2=F or group2=G or group2=H or group2=S and
     EOD663=yes then except=yes gcompat=Y;

RULE Note_4
     if group2=F and group1=C or group1=D or group1=E and
     UNI=UN0292 then except=yes gcompat=Y;

RULE Note_5a
     if group2=G and UNI=UN0300 or UNI=UN0301 or UNI=UN0325
     then except=yes group2=S;

RULE Note_5b
     if group1=G and UNI=UN0300 or UNI=UN0301 or UNI=UN0325
     then except=yes group1=S;
```

```
RULE Note_6
     if group2=G and group1>=C and group1<=E and UNI=UN0018
     or UNI=UN0314 or UNI=UN0315 or UNI=UN0317 or UNI=UN0319
     or UNI=UN0320 then except=yes gcompat=Y;

RULE Note_7
     if group1=yes and group1=L or group2=L then
     color=30
     display" \\************ CAUTION***************//"
     color=15
     display"Group L items must only be loaded with
identical items.
                    Press any key to continue~"
     group1=no
     except=yes

!******* No note exceptions **********************
     else except=not;

!******** DATA INPUT SECTION**********************

ASK element:"Identify all hazardous cargo items one at a
time by highlighting the items using the arrow keys and
pressing <enter>.  (Do not select more than 9 items!  Only
the first nine items will be compared.)

When finished, select 'No more items'.  ****->>  Current
item: {i} ";

CHOICES
element:1.1_Explosive,1.2_Explosive,1.3_Explosive,1.4_Explos
ive,1.5D_Explosive,1.6N_Explosive,2.1_Flammable_Gas,2.2_NonT
ox_NonFlam_Gas,2.3A_PoisGas_Zone_A,2.3O_Pois_Gas_Other,3.0_F
lammable_Liquid,4.1_Flammable_Solid,4.2_Spontan_Combustible,
4.3_Haz_When_Wet,5.1_Oxidizer,5.2_Organic_Perox,6.1_Poison_L
iquid,7.0_Radioactive,8.0_Corrosive_Liquid,9.0_Other,
No_more_items;

ASK g1.1:"Enter the group(s) for element(s) with class
1.1:";

CHOICES g1.1: A,B,C,D,E,F,G,J,L;

ASK g1.2:"Enter the group(s) for element(s) with class
1.2:";

CHOICES g1.2: B,C,D,E,F,G,H,J,K,L;

ASK g1.3:"Enter the group(s) for element(s) with class
1.3:";

CHOICES g1.3: C,F,G,H,J,K,L;
```

```
ASK g1.4:"Enter the group(s) for element(s) with class
1.4:";

CHOICES g1.4: B,C,D,E,F,G,S;

ASK priority:
  "Enter the priority for item {element} (from 1 to 9):";

RANGE priority:1,9;

ASK again:"          Do you wish to run this program again?";

CHOICES again:Yes,No;

ASK fissile_III:"Does your class 7 item contain Fissile
Class III radioactive material?";

CHOICES fissile_III:yes,no;

ASK radio_solid:"Is your class 7 item normal uranium,
depleted uranium, or thorium metal in solid form?";

CHOICES radio_solid:yes,no;

ASK cyanides:"Is your class 6.1 item a cyanide or cyanide
mixture?";

CHOICES cyanides:yes,no;

ASK nitric:"Is your class 8 item Nitric Acid?";

CHOICES nitric:yes,no;

ASK EOD663:"Are you using an EOD MK 663, MOD O container for
your group B explosive?";

CHOICES EOD663:yes,no;

ASK UNI:"Are you shipping any of the following UN numbers?";

CHOICES
UNI:UN0009,UN0018,UN0019,UN0257,UN0292,UN0300,UN0301,UN0314,
UN0315,UN0317,UN0319,UN0320,UN0325,UN0408,UN0409,NO;
```

Turbo Pascal Programs for Numerical Manipulation of Data entered in VPExpert.

PROGRAM Hazdis;

{Display of output from HAZARD expert system}


```
TYPE
  FDATA  =  STRING[20];

VAR
  ELEMENT                          : ARRAY[1..55] OF FDATA;
  COMPATR                          : ARRAY[1..55] OF CHAR;
  OPTION,ANS,CHANGE,ANS1      : CHAR;
  ELEMENTS,COMPAT,ELE_ORD,PFILE    : TEXT;
  I,J,K,L,M,N,Y,MAX_ELEMENTS   : INTEGER;
  MAX_COMPARISONS                  : INTEGER;
  TOT_ELEMENTS,CCOUNT              : INTEGER;
  COMPATABILITY                    : STRING[17];
  E1,E2                            : ARRAY[1..55] OF STRING[4];
  LEAVE                            : STRING[3];
  YES_STACK,NO_STACK               : ARRAY[1..55] OF STRING[4];
  STACKNO,STACKYES                 : INTEGER;
  ENDYES,ENDNO,CHALKNO             : INTEGER;
  HIGH                             : STRING[4];
  HIGH_COUNT                       : INTEGER;
  CHALK                            : ARRAY[1..15,1..15,1..2] OF
STRING[4];                          {CHALK #, CHALK ELE}
  NEW_CHALK                        : INTEGER;
  PRIORITY                         : ARRAY[1..55] OF STRING[4];
  MOVE_CHOICES                     : ARRAY[1..15] OF INTEGER;
  PRINTER                          : string[2];


PROCEDURE PRINT_DEF;

begin
 clrscr;
 gotoxy(5,10);
 writeln('Are you using a printer that supports the extended
 character set');
 write('                     for box characters (Y/N)?');
 read(kbd,ans1);
 ans1:=upcase(ans1);
 if ans1='Y' then printer:='go'
 else printer:='no';
end;   {procedure}


PROCEDURE CLEAR_LINES;
```

```
BEGIN
  FOR M:=22 TO 25 DO BEGIN
  GOTOXY(1,M);
  CLREOL;
  END;
  GOTOXY(1,22);
END;   {PROCEDURE}



FUNCTION COM_COL(COMPATR : CHAR) : INTEGER;
BEGIN
  CASE COMPATR OF
  'N' : COM_COL:=12;          {LIGHT RED}
  'Y' : COM_COL:=10;          {LIGHT GREEN}
  'C' : COM_COL:=14;          {YELLOW}
  END;   {CASE}
END;       {FUNCTION}


PROCEDURE PLOT_DATA;


BEGIN
 TEXTCOLOR(15);
 FOR I:=1 TO MAX_ELEMENTS DO BEGIN
 GOTOXY(2,2+I*2);
 WRITE(ELEMENT[MAX_ELEMENTS-I+1]);
 GOTOXY(18+I*6,2);
 WRITE(COPY(ELEMENT[MAX_ELEMENTS-I+1],1,4));
END;
 TEXTCOLOR(15);
 CCOUNT:=0;
 FOR I:=MAX_ELEMENTS DOWNTO 1 DO        {Y ELEMENT VERTICAL}
    FOR J:=I-1 DOWNTO 1 DO BEGIN        {X ELEMENT HORIZONTAL}
    CCOUNT:=CCOUNT+1;
    GOTOXY(20+J*6,2+I*2);
    TEXTCOLOR(COM_COL(COMPATR[CCOUNT]));
    WRITE(COMPATR[CCOUNT]);
    GOTOXY(20+I*6,2+J*2);
    WRITE(COMPATR[CCOUNT]);
    END;
    GOTOXY(1,24);                          {GET CURSER OUT OF WAY}
    REPEAT UNTIL (KEYPRESSED) OR (PRINTER='go');
END;   {PROCEDURE PLOT_DATA}


PROCEDURE GRAPH;

{display physical graph outline to be filled by data}

BEGIN
```

```
    CLRSCR;
    TEXTMODE(C80);
    TEXTBACKGROUND(1);
    TEXTCOLOR(11);
    WRITELN(' Read Chart Across to Determine Compatibility');
        TEXTCOLOR(15);
```



```
    TEXTCOLOR(11);
    WRITE  ('        LEGEND:    ');
    TEXTCOLOR(10);
    WRITELN('Y = Items are compatible          ');
    TEXTCOLOR(12);
    WRITELN('N = Items are not compatible      ');
    TEXTCOLOR(14);
    WRITELN('C = Conditionally compatible, items must be
             separated by 88" ');
    TEXTCOLOR(13);
    WRITE  ('****  PRESS ANY KEY TO CONTINUE  ***** ');
    PLOT_DATA;
END;  {PROCEDURE GRAPH}

PROCEDURE NUM_ELEMENTS;
BEGIN
 {GET DATA FROM ELEMENTS.DAT (FULL NAME), COMPAT.DAT (Y OR
N), AND ELEMENT.TAD}
 FOR I:=1 TO 55 DO BEGIN
 COMPATR[I]:=' ';
 ELEMENT[I]:=' ';
 PRIORITY[I]:=' ';
 END;
 I := 0;
 ASSIGN(ELEMENTS,'ELEMENTS.DAT');
  RESET(ELEMENTS);
```

```
  ASSIGN(PFILE,'PRIORITY.DAT');
   RESET(PFILE);
  WHILE NOT EOF(ELEMENTS) DO BEGIN
     I:=I+1;
     READLN(ELEMENTS,ELEMENT[I]);
     READLN(PFILE,PRIORITY[I]);
  END;  {WHILE}
   CLOSE(PFILE);
   MAX_ELEMENTS:=I;

   {GET DATA FROM ELEMENTS.TAD AND COMPARE.DAT: JUST CLASS
AND COMPATABILITY}
  ASSIGN(ELE_ORD,'ELEMENTS.TAD');
   RESET(ELE_ORD);
  ASSIGN(COMPAT,'COMPAT.DAT');
   RESET(COMPAT);
   I:=0;
   WHILE NOT EOF(ELE_ORD) DO BEGIN
     I:=I+1;
    READLN(ELE_ORD,E1[I]);
    READLN(ELE_ORD,E2[I]);
    READLN(COMPAT,COMPATR[I]);
  END;  {WHILE}
   MAX_COMPARISONS:=I;
   CLOSE(ELE_ORD);
   CLOSE(COMPAT);
END;   {PROCEDURE NUM_ELEMENTS}

PROCEDURE PRINT;

BEGIN
PRINT_DEF;
IF PRINTER='go' THEN BEGIN
  GRAPH;
  WRITELN(LST,CHR(27),'(10U');
  INLINE($CD/$05);              {PRINT SCREEN}
  PRINTER:=' ';
END                            {PRINTER=GO}
ELSE BEGIN
  WRITELN(LST,'Compatibility Determination of the following
elements:');
 WRITELN(LST);
 FOR I:=1 TO MAX_COMPARISONS DO BEGIN
   IF COMPATR[I]='Y' THEN COMPATABILITY:='ARE'
   ELSE IF COMPATR[I]='N' THEN COMPATABILITY:='ARE NOT'
   ELSE IF COMPATR[I]='C' THEN COMPATABILITY:='ARE
Conditionally'
   ELSE COMPATABILITY:=COMPATR[I];
   WRITELN(LST,'Elements ',E1[I],' AND ',E2[I],'
',COMPATABILITY,'                    compatible.');
  END;       {FOR}
END;         {ELSE}
```

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```
WRITE(LST,CHR(12));                          {FORM FEED}
END;          {PROCEDURE PRINT}

PROCEDURE CHALK_DISPLAY;

BEGIN
 CLRSCR;
 TEXTCOLOR(15);
 WRITELN('          Chalk Listings Based on Compatibility
(Element,Priority)');
 WRITELN;
 TEXTCOLOR(0);
 WRITELN('          1         2         3         4         5
6         7         8');
 TEXTCOLOR(15);
 WRITELN('     Cls/Pri  Cls/Pri  Cls/Pri  Cls/Pri  Cls/Pri
Cls/Pri  Cls/Pri  Cls/Pri');
 WRITELN('

_____');
 FOR I:=1 TO 15 DO BEGIN      {element}
 WRITELN;
   TEXTCOLOR(0);
   WRITE(' ',CHR(64+I),'. ');              {element row letter}
   FOR J:=1 TO 8 DO                        {chalk number}
     IF COPY(CHALK[J,I,1],1,1)<>' ' THEN  BEGIN
                                          {if class not blank}
     TEXTCOLOR(15);
      WRITE(CHALK[J,I,1],',');                   {class}
      TEXTCOLOR(14);
      WRITE(COPY(CHALK[J,I,2],1,1),'    ');    {priority}
    END  {IF THEN}
     ELSE
     WRITE('          ');                   {space when blank}
END;   {FOR I}
   WRITELN;
   TEXTCOLOR(15);
   WRITELN ('Your options are to 1. M ove an item
           2. D isplay the matrix');
   WRITELN ('3. P rint the Screen  4. R erun the program.');
   WRITE    ('                      5. e X it the program');
END; {PROCEDURE CHALK_DISPLAY}


PROCEDURE MOVE_NOW;

BEGIN
  K:=1;                {ADD ITEM TO NEW CHALK IN RIGHT ORDER}
  REPEAT
  IF CHALK[NEW_CHALK,K,1]<CHALK[J,I,1] THEN BEGIN
  FOR M:=14 DOWNTO K DO
```

```
      FOR N:=1 TO 2 DO  CHALKLK [NEW_CHALK,M+1,N]:=CHALK
         [NEW_CHALK,M,N];
      FOR N:=1 TO 2 DO CHALK[NEW_CHALK,K,N]:=CHALK[J,I,N];
                                           {MOVE ITEM}
       K:=14;
    END;  {IF CHALK}
      K:=K+1;
     UNTIL K>14;
     FOR K:=I TO 14 DO          {DELETE ITEM FROM EXISTING CHALK}
     FOR N:=1 TO 2 DO
     CHALK[J,K,N]:=CHALK[J,K+1,N];
     FOR N:=1 TO 2 DO CHALK[J,15,N]:=' ';    {DELETE 15TH ITEM}
END;  {PROCEDURE MOVE_NOW}


PROCEDURE MOVE_ITEM;

BEGIN
  CLEAR_LINES;
  WRITELN('                      Move  Item  Routine:');
  WRITELN(' Select item to move (row LETTER and chalk column
  NUMBER: i.e. A3)');
  WRITE('          or EXIT without moving by typing "X" :');
  TEXTCOLOR(15);
  REPEAT
  READ(KBD,ANS);
  ANS:=UPCASE(ANS);
  UNTIL ANS IN ['A'..'O','X'];
  IF ANS='X' THEN BEGIN
  CHALK_DISPLAY;
  EXIT;
  END;
  I:=ORD(ANS)-64;
  WRITE(ANS);
  REPEAT
  READ(KBD,ANS);
  UNTIL ANS IN ['1'..'9'];
  J:=ORD(ANS)-48;
  WRITE(J);
  WRITELN;
  IF COPY(CHALK[J,I,1],1,1) = ' ' THEN BEGIN
  CLRSCR;
  GOTOXY(15,10);
  TEXTCOLOR(12);
  WRITELN('    ****** INVALID ELEMENT SELECTED ********');
  DELAY(1900);
  CHALK_DISPLAY;
  EXIT;
END;  {IF COPY=' '}
  {WHEN VALID}
  FOR K:=1 TO 15 DO MOVE_CHOICES[K]:=0;    {CLEAR ARRAY}
  CCOUNT:=1;                       {chalk count initialization}
```

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```
      FOR K:=1 TO 9 DO                        CHALKNO}
      IF COPY(CHALK[K,1,1],1,1)<>' ' THEN BEGIN    {if chalk is
                                                  not empty}
       ANS:='Y';                               {inital value}
       FOR M:=1 TO 15 DO              {ELEMENT IN CHALK}
       FOR N:=1 TO MAX_COMPARISONS DO    {E1 E2 COMPATR counter}
       IF CHALK[J,I,1] > CHALK[K,M,1] THEN  BEGIN
       IF (CHALK[J,I,1] = E1[N]) AND (CHALK[K,M,1] =
       E2[N]) AND (COMPATR[N]='N')
       THEN ANS:='N';     {chalk is not compatible}
      END {IF >}
        ELSE    {FIRST IF}
        IF (CHALK[K,M,1] = E1[N]) AND (CHALK[J,I,1] = E2[N]) AND
           (COMPATR[N]='N') THEN ANS:='N';        {END OF FOR N}
          {END OF FOR M}
         IF ANS='Y' THEN BEGIN                {chalk is compatible}
         MOVE_CHOICES[CCOUNT]:=K;           {save chalk name}
         CCOUNT:=CCOUNT+1;
         END;   {IF ANS=Y}
        END;   {IF COPY CHALK K}

   MOVE_CHOICES[CCOUNT]:=CHALKNO+1;     {option to add a chalk}
   CLEAR_LINES;
   WRITE('The only available chalks for item ',CHALK[J,I,1],'
         are: ');
   FOR K:=1 TO CCOUNT DO WRITE(MOVE_CHOICES[K],', ');
   WRITELN(CHR(8),CHR(8),'.');
   WRITE('Enter the chalk number to which you wish to move:');
   REPEAT
   READ(KBD,ANS);
   UNTIL ANS IN ['1'..'9'];
   NEW_CHALK:=ORD(ANS)-48;        {convert character to number}
   IF NEW_CHALK=CHALKNO+1 THEN CHALKNO:=CHALKNO+1;
   ANS:='N';
   FOR K:=1 TO CCOUNT DO
   IF MOVE_CHOICES[K]= NEW_CHALK THEN BEGIN   {check if valid
                                              chalk}
   MOVE_NOW;
    ANS:='Y';
    K:=CCOUNT;      {to exit loop}
   END;  {if move}
      {end for k}
    IF ANS='N' THEN BEGIN     {when desired chalk is incomp}
    CLEAR_LINES;
   WRITELN('The chalk you selected is not compatible with the
   item you identified.');
    WRITE('Do you wish to move ',CHALK[J,I,1],' to chalk
    ',NEW_CHALK,' on a waiver (Y/N)? ');
   REPEAT
     READ(KBD,ANS);
     ANS:=UPCASE(ANS);
     UNTIL ANS IN ['Y','N'];
```

```
      IF ANS='Y' THEN MOVE_NOW;
   END; {IF ANS=N}
   CHALK_DISPLAY;
END;  {PROCEDURE MOVE_ITEM}


PROCEDURE GROUP;

BEGIN
   CLRSCR;
   GOTOXY(1,1);
   FOR I:=1 TO 15 DO BEGIN
      YES_STACK[I]:=' ';
      NO_STACK[I]:=' ';
   END;
   {FILL YES STACK WITH ALL ELEMENTS BEFORE CHECKING
COMPATABILITY}
   FOR I:=1 TO 15 DO FOR J:=1 TO 15 DO FOR K:=1 TO 2 DO
   CHALK[I,J,K]:=' ';
   YES_STACK[1]:=E1[1];
   FOR I:=1 TO MAX_ELEMENTS-1 DO YES_STACK[I+1]:=E2[I];
   ENDYES := MAX_ELEMENTS;
   ENDNO := 0;

{CROSS REFERENCE YES STACK WITH EACH OTHER}
   CHALKNO:=0;
   REPEAT                          {UNTIL ALL CHALKS ARE COMPLETE}
   CHALKNO:=CHALKNO+1;
   I:=1;
   REPEAT                       {FIRST ELEMENT OF COMPARISON}
   J:=I+1;
   REPEAT                       {SECOND ELEMENT OF COMPARISON}
   FOR K:=1 TO MAX_COMPARISONS DO {CHECK E1 AND E2 LIST TO
                                   FIND MATCH}
   BEGIN CHANGE:='N';
   IF (E1[K]=YES_STACK[I]) AND (E2[K]=YES_STACK[J]) AND
   (COMPATR[K]='N') THEN BEGIN      {PLACE ITEM ON NO_STACK
                                     IN DECREASING ORDER}
    L:=0;
    REPEAT L:=L+1; UNTIL YES_STACK[J] > NO_STACK[L];
    FOR N:=ENDNO DOWNTO L DO NO_STACK[N+1]:=NO_STACK[N];
    {PUSH STACK}
    NO_STACK[L]:=YES_STACK[J];
    ENDNO:=ENDNO+1;
    FOR L:=J TO ENDYES DO YES_STACK[L]:=YES_STACK[L+1];
    {PACK STACK}
    YES_STACK[ENDYES]:=' ';
    ENDYES:=ENDYES-1;
    CHANGE:='Y';
   END;  {IF TRUE, TRANSFER IS MADE}
   END;  {FOR K -> NEXT E1 AND E2}
     IF CHANGE='N' THEN J:=J+1;
```

```
        UNTIL J>ENDYES;
        IF CHANGE='N' THEN I:=I+1;
        UNTIL I>ENDYES-1;
        {TRANSFER YES TO CHALK, NO TO YES, AND CLEAR NO FOR NEXT
         CHECK}
        FOR I:=1 TO 15 DO BEGIN
        CHALK[CHALKNO,I,1]:=YES_STACK[I];
        YES_STACK[I]:=NO_STACK[I];
        NO_STACK[I]:=' ';
       END; {FOR I}

        ENDYES:=ENDNO;
        ENDNO:=0;
        UNTIL ENDYES=0;                              {LAST CHALK}
        FOR I:=1 TO 15 DO FOR J:=1 TO 9 DO FOR K:=1 TO
        MAX_ELEMENTS DO IF CHALK[I,J,1]=COPY(ELEMENT[K],1,4)
        THEN CHALK[I,J,2]:=PRIORITY[K]; CHALK_DISPLAY;
        LEAVE:='NO';
        REPEAT
        READ(KBD,ANS);
        CASE ANS OF
        '2','D','d' : BEGIN
        GRAPH;
        CLEAR_LINES;
        WRITE('Press P to PRINT or any other key to return to
                chalks.');
        READ(KBD,ANS);
        IF (ANS='P') OR (ANS='p') THEN PRINT;
        CHALK_DISPLAY;
       END;
          '3','p','P' : BEGIN
          INLINE($CD/$05);                   {PRINT SCREEN}
          WRITE(LST,CHR(12));                   {FORM FEED}
       END;
          '1','M','m' : MOVE_ITEM;
          '4','R','r' : BEGIN
          REWRITE(ELEMENTS);
          WRITELN(ELEMENTS,'yes');
          WRITELN(ELEMENTS,'yes');
          CLOSE(ELEMENTS);
          LEAVE:='YES';
         END;  {5 OPTION}
          '5','X','x' : BEGIN
          REWRITE(ELEMENTS);
          WRITELN(ELEMENTS,'no');
          WRITELN(ELEMENTS,'yes');
          CLOSE(ELEMENTS);
          LEAVE:='YES';
       END;  {4 OPTION}
         END;  {CASE}
          UNTIL LEAVE='YES';
       END;    {PROCEDURE GROUP}
```

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```pascal
PROCEDURE MENU;

BEGIN
  LEAVE:='NO';
  REPEAT
  GRAPH;            {PRINTS OUT MATRIX STRUCTURE AND DATA}
  CLEAR_LINES;              {CLEARS BOTTOM FIVE LINES}
  GOTOXY(1,22);
  TEXTCOLOR(11);
  WRITELN('**** Options (Press number or letter):  **** ');
  WRITELN;
  WRITELN('1. Print Results  3. Rerun the Program');
  WRITE ('2. S elect Possible Item Groupings    4. Q uit ');
  READ(KBD,OPTION);
  CASE OPTION OF
       '1','P','p' : PRINT;
       '2','S','s' : GROUP;
       '3','R','r' :
    BEGIN
    REWRITE(ELEMENTS);
    WRITELN(ELEMENTS,'yes');
    WRITELN(ELEMENTS,'yes');
    CLOSE(ELEMENTS);
    LEAVE:='YES';
   END;  {3 OPTION}
     '4','Q','q' :
    BEGIN
    REWRITE(ELEMENTS);
    WRITELN(ELEMENTS,'no');
    WRITELN(ELEMENTS,'yes');
    CLOSE(ELEMENTS);
    LEAVE:='YES';
   END;  {4 OPTION}
  END;    {CASE}
    UNTIL LEAVE='YES';
  END;      {PROCEDURE MENU}

 BEGIN
   NUM_ELEMENTS;              {INPUT DATA}
   MENU;                      {OPTIONS FOR PRINTING AND GROUPING}
 END.

PROGRAM CROSSREF;
{this program will take hazardous classes from elements.dat
and cross reference them against one another, then rewrite
the crossed pairs back to elements.tad}

Type
  fdata    = string[4];
Var
  elements                    : array[1..50] of fdata;{50 data
  elements max}
```

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```pascal
ele_long                    : array[1..50] of string[20];
infile,outfile,prio_file : text;
I,J,K,dat_elements          : Integer;
prio                        : array[1..50] of char;
new_element                 : string[20];
new_prio                    : char;

PROCEDURE DATA_IN;

  begin
   Assign(infile,'elements.dat');
   reset(infile);
   assign(prio_file,'priority.dat');
   reset(prio_file);
   for i:=1 to 50 do begin                {clear arrays}
   ele_long[i]:=' ';
   prio[i]:=' ';
   elements[i]:=' ';
  end;
    I:=0;
    while (not EOF(infile)) and (I<9) do begin
    I:=I+1;
    readln(prio_file,new_prio);
    readln(infile,new_element);        {read in data from file
                                        to var: elements}
    j:=0;
    repeat        {sort new element in order large->small}
    j:=j+1;
    if new_element>ele_long[j] then begin
    for k:=i downto j+1 do begin
    ele_long[k]:=ele_long[k-1];
    prio[k]:=prio[k-1];
   end;                          {for k}
    ele_long[j]:=new_element;
    prio[j]:=new_prio;
    j:=i;
   end;                                {new element>ele_long}
    until j=i;
   end;                                    {while}
    dat_elements:=i;        {number of data elements input}
    rewrite(infile);
    rewrite(prio_file);
    for j:=1 to i do begin                {rewrite sorted files}
    writeln(infile,ele_long[j]);
    elements[j]:=copy(ele_long[j],1,4);
    writeln(prio_file,prio[j]);
   end;
    close(prio_file);
    close(infile);
   end;                                    {procedure DATA_IN}
```

```
PROCEDURE CROSS;   {cross reference data & write to file}

begin
  Assign(outfile,'elements.tad');
  rewrite(outfile);              {clear contents of file}
  for i:=1 to (dat_elements-1) do
  for j:=(i+1) to dat_elements do begin
  writeln(outfile,elements[i]); {first of pair to be
                                 compared -> file}
  writeln(outfile,elements[j]);   {second of pair -> file}
 end;                            {j}
  close(outfile);
end;                                     {procedure cross}

Begin {main}
  DATA_IN;             {save data from elements.dat to var}
  CROSS;        {perform cross reference and write to file}
end.          {main}
```

Appendix C: Software Users Manual

Introduction

HAZARD is a user-friendly expert system which incorporates the rules and logic of AFR 71-4 to aid in the determination of hazardous cargo compatibility destined for military air transportation. The program has been tested by personnel at HQ/AMC and HQ/AFMC. The rules incorporated in HAZARD comply with the new international guidelines for hazardous materials transportation and the January 1993 version of Air Force Regulation 71-4, which is based on these international standards.

Installation

The HAZARD program requires an IBM personal computer or compatible. While the program can run from a floppy diskette, a hard drive is recommended for access speed. To install the software on a hard drive, simply copy the contents of the floppy diskette into a directory. This can be accomplished with the following steps:

```
1)   Place the floppy diskette in the a: drive
2)   Type "c:" <ENTER>
3)   Type "md hazard" <ENTER>
4)   Type "cd hazard" <ENTER>
5)   Type "copy a:*.*"<ENTER>
```

All the files necessary to use HAZARD are now on the hard drive in a directory called hazard.

Running HAZARD

This section outlines the steps to run HAZARD.

1) Change to the HAZARD directory.
2) Type "GO" <ENTER>

The program will load and an introduction screen will appear

on the monitor (Figure 1). Press any key to continue.

Welcome to HAZARD, a hazardous cargo compatibility determination program based on the AFR 71-4 (Jan 93) guidelines which follow international rules.

An Expert System by:
Captain Douglas Furst, USAF
and
Captain Ronald Smith, USAF

HAZARD identifies the compatibility of hazardous cargo items, and provides recommendations for chalk groupings based on compatibility and priority rules. Compatibility is determined by the CLASS and/or GROUP of hazardous items. Incompatible items are not permitted to travel concurrently by military mode. During contingencies, some restrictions may be waived by HQ/AMC (See chapter 3 in AFR 71-4).

Press any key to begin HAZARD:

Figure 1. Introductory Screen

Entering Hazardous Class, Priority and Group

After following the instructions on the screen, a list

of cargo classes will appear (Figure 2). To enter the

classes of hazardous cargo that are to be shipped, simply
highlight the class using the arrow keys and press "enter".

```
///////    Cargo Compatibility Determination  \\\\\\

Identify all hazardous cargo items one at a time by highlighting
the items using the arrow keys and pressing <enter>.  (Do not select more
than 9 items!  Only the first nine items will be compared.)

        When finished, select 'No more items'.   ****->>  Current item: 1

   1.1 Explosive         1.2 Explosive         1.3 Explosive
   1.4 Explosive         1.5D Explosive        1.6N Explosive
   2.1 Flammable Gas     2.2 NonTox NonFlam G  2.3A PoisGas Zone A
   2.30 Pois Gas Other   3.0 Flammable Liquid  4.1 Flammable Solid
   4.2 Spontan Combusti  4.3 Haz When Wet      5.1 Oxidizer
   5.2 Organic Perox     6.1 Poison Liquid     7.0 Radioactive
   8.0 Corrosive Liquid  9.0 Other             No more items
```

Figure 2.   Hazardous Cargo Class Entry

If an explosive is identified for shipment, the
computer will request the group of each explosive class.
Use the arrow keys to identify the appropriate class and
press "enter" (Figure 3).

After each cargo class is entered, the computer asks
for the transportation priority of each item (Figure 4).
Input the priority by typing in a number from 1 to 9.

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```
┌─────────────────────────────────────────────────────────┐
│                                                         │
│  Enter the group(s) for element(s) with class 1.1:      │
│   A                      B                      C        │
│   D                      E                      F        │
│   G                      J                      L        │
│                                                         │
│                                                         │
│                                                         │
│                                                         │
│                                                         │
│                                                         │
│                                                         │
│                                                         │
│                                                         │
│                                                         │
└─────────────────────────────────────────────────────────┘
```

Figure 3.   Explosive Group Menu

The process of entering data continues for each item. If an item is mistakenly entered, move to that item and press the "delete" key to delete the entry. Due to screen limitations, the number of items entered must be less than ten. A counter is provided on the screen which provides the current entry number.

Use of Notes and United Nation Numbers in HAZARD

All the notes associated with the AFR 71-4 compatibility tables have been incorporated into HAZARD and are automatically referenced when applicable. If for

```
Identify all hazardous cargo items one at a time by highlighting
the items using the arrow keys and pressing <enter>.  (Do not select more
than 9 items!  Only the first nine items will be compared.)

        When finished, select 'No more items'.   ****->>  Current item: 3

1.1 Explosive          1.2 Explosive          1.3 Explosive
1.4 Explosive          1.5D Explosive         1.6N Explosive
2.1 Flammable Gas      2.2 NonTox NonFlam G   2.3A PoisGas Zone A
2.3O Pois Gas Other    3.0 Flammable Liquid   4.1 Flammable Solid
4.2 Spontan Combusti   4.3 Haz When Wet       5.1 Oxidizer
5.2 Organic Perox      6.1 Poison Liquid      7.0 Radioactive
8.0 Corrosive Liquid ◄ 9.0 Other              No more items


Enter the priority for item 8.0 Corrosive Liquid (from 1 to 9):
  3█
```

Figure 4.   Item Priority Menu

example, one of the items is 7.0 radioactive

material, a question will appear on the screen asking

whether or not it is Fissile Class III (Figure 5).

Highlight the proper response and press "enter".

United Nations (UN) numbers are also included as part

of the notes in the program. The UN numbers listed

correspond to specific cargo items that may be an exception

to the standard rules. Questions pertaining to UN notes,

like all other questions on notes, only appear when required

based on earlier data input. The same procedure applies to

answering questions pertaining to notes as entering other

data; highlight the response and press enter.

```
                      Please wait,
        ////////   Cross referencing data input.   \\\\\\\\

//////  Compatibility rules are being applied to the combinations  \\\\\\
Does your class 7 item contain Fissile Class III radioactive material?
 yes ◄                        no

Is your class 8 item Nitric Acid?
 yes                          no ◄

Are you shipping any of the following UN numbers?
  UN0009                  UN0018 ◄            UN0019
  UN0257                  UN0292              UN0300
  UN0301                  UN0314              UN0315
  UN0317                  UN0319              UN0320
  UN0325                  UN0408              UN0409
  NO

Are you using an EOD MK 663, MOD 0 container for your group B explosive?
 yes                          no
```

Figure 5.   Use of Notes Through Questions

Compatibility Results

Upon completion of all data input, a new screen will
appear with a matrix showing whether or not the items are
compatible for shipment (Figure 6). After examining the
compatibility matrix, press any key to reveal a menu.
Several options will appear: Print, Select, Rerun or Quit.

```
Read Chart Across to Determine Compatibility
                        1.1A  1.2B  2.1_  2.3A  3.0_  4.2_  5.1_
1.1A_Explosive           •     N     N     N     N     N     N
1.2B_Explosive)          N     •     N     N     N     N     N
2.1_Flammable_Gas        N     N     •     N     Y     C     C
2.3A_PoisGas_Zone_A      N     N     N     •     N     N     N
3.0_Flammable_Liquid     N     N     Y     N     •     C     C
4.2_Spontan_Combusti     N     N     C     N     C     •     Y
5.1_Oxidizer             N     N     C     N     C     Y     •

       LEGEND:   Y = Items are compatible
                 N = Items are not compatible
                 C = Conditionally compatible, items must be separated by 88"
       *****  PRESS ANY KEY TO CONTINUE  *****
```

Figure 6.   Sample of Matrix

Print. Press "P" or "1" to choose the print option.
After entering all the data for the cargo, the computer will
ask if the connected printer supports the extended character
set for boxed characters (Figure 7). If the printer is
capable of emulating an Epson, Hewlett-Packard Laserjet, or
IBM printer, the answer is yes. The ALPS 2000 has emulation
capability. To answer, type either "Y" or "N". The
compatibility matrix shown on the screen will print as seen.

Select. Press "S" or "2" to choose the select option.
This option organizes the hazardous items into suggested
chalk listings based on compatibility (Figure 7). See Using
the Select Option for further details.

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```
        Chalk Listings Based on Compatibility  (Element,Priority)

       1       2       3       4       5       6       7       8
    Cls/Pri Cls/Pri Cls/Pri Cls/Pri Cls/Pri Cls/Pri Cls/Pri Cls/Pri
   _____

 A. 8.8_,2  7.8_,1  1.1B,1
 B. 4.1_,2
 C. 1.5D,1
 D.
 E.
 F.
 G.
 H.
 I.
 J.
 K.
 L.
 M.
 N.
 O.
Your options are to 1. M ove an item       2. D isplay the matrix
                    3. P rint the Screen   4. R erun the program.
                    5. e X it the program
```

Figure 7.   Suggested Chalk Listing

Rerun. Press "R" or "3" to return to the data entry
screen (Figure 2). This option erases all the data
previously entered allowing new data to be entered.

Quit. By pressing "Q" or "4, the screen in Figure 8
will appear. From this screen press any key to return to
the DOS prompt.

Using the Select Option

By choosing the Select option from the matrix screen,
the five options in Figure 7 are available: Move, Display,
Print, Rerun and Exit.

```
┌──────────────────────────────────────────────────┐
│                                                    │
│                                                    │
│   ┌────────────────────────────────────────────┐   │
│   │ Thank you for using Hazard, safe transporting.│  │
│   │      (Press any key to exit.)                │   │
│   │                                              │   │
│   │                                              │   │
│   │                                              │   │
│   │                                              │   │
│   │                                              │   │
│   │                                              │   │
│   │                                              │   │
│   │                                              │   │
│   │                                              │   │
│   │                                              │   │
│   │                                              │   │
│   └────────────────────────────────────────────┘   │
│                                                    │
│                                                    │
└──────────────────────────────────────────────────┘
```
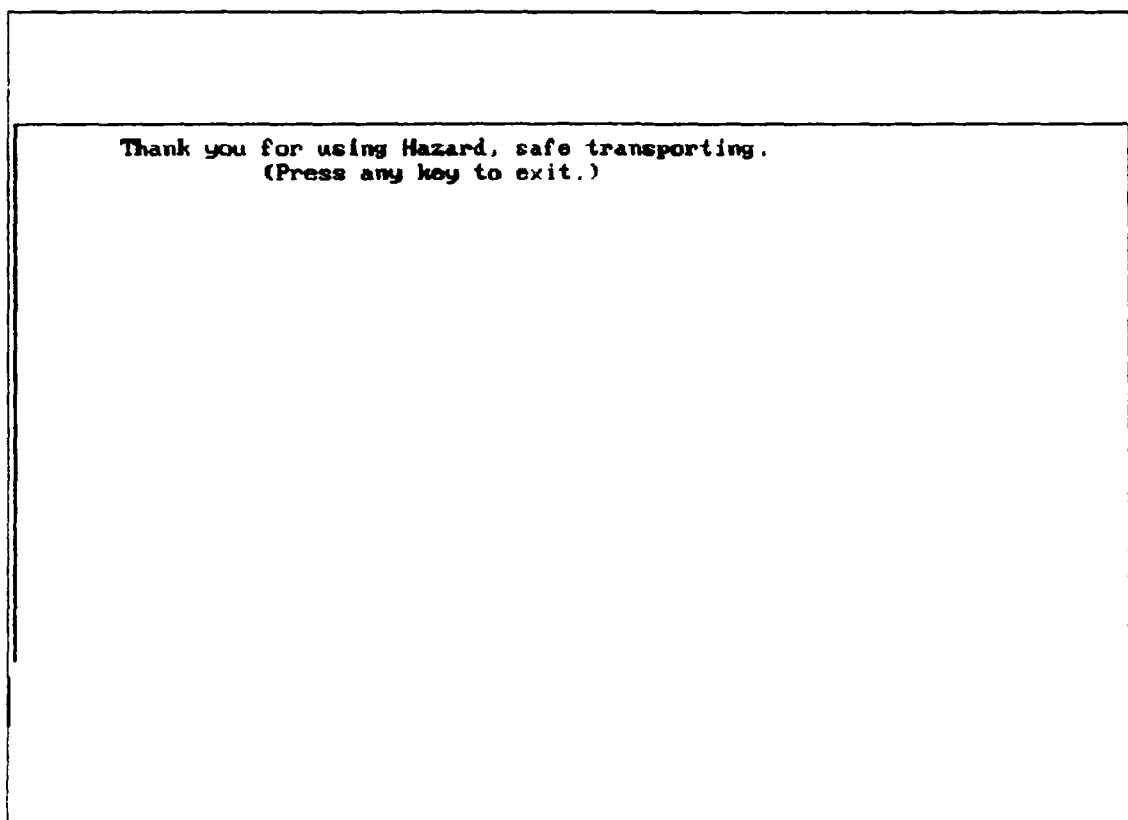
Figure 8.   Returning to DOS

Move. The select option only provides one possible
combination of item groupings. In case another item
grouping is desired, a move function is offered by pressing
"M" or "1".   To move an item from one chalk to another,
identify the item by typing the row letter and column
number. In this example (Figure 9), item 4.1,_2 would be
identified by typing "B1". Based on compatibility rules,
the computer will identify other chalks to which the
selected item may be moved. The last chalk number
recommended by the computer, provides the option to start a
new chalk (Figure 10). To place the item in any chalk, type
the chalk number.

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```
Chalk Listings Based on Compatibility  (Element,Priority)

         1        2        3        4        5        6        7        8
      Cls/Pri  Cls/Pri  Cls/Pri  Cls/Pri  Cls/Pri  Cls/Pri  Cls/Pri  Cls/Pri
     ────────────────────────────────────────────────────────────────────────
A.  8.0_,2   7.0_,1   1.1B,1
B.  4.1_,2
C.  1.5D,1
D.
E.
F.
G.
H.
I.
J.
K.
L.
M.
N.
O.
                        Move  Item  Routine:
    Select item to move (row LETTER and chalk column NUMBER: i.e. A3)
            or EXIT without moving by typing "X" :
```

Figure 9.   Move Item Routine

Any chalk may be selected for the item. However, if
the item which is being moved is not compatible with the
items in the desired chalk, a question prompts the user if
there are plans to obtain a waiver that permits these items
to be shipped together (Figure 11). If yes, the item is
moved to that chalk. By selecting no, the item stays in its
original position. To answer whether or not a waiver
pertains to the item being moved, type either "Y" or "N" and
press enter. If an item is mistakenly entered, simply
select its original chalk number to return the item to its
starting point.

```
+--------------------------------------------------------------+
|                                                              |
|      Chalk Listings Based on Compatibility  (Element,Priority)|
|                                                              |
|      1       2       3       4       5       6       7       8|
|    Cls/Pri Cls/Pri Cls/Pri Cls/Pri Cls/Pri Cls/Pri Cls/Pri Cls/Pri|
|   _____ |
|                                                              |
| A. 8.8_,2  7.8_,1   1.1B,1                                    |
| B. 4.1_,2                                                    |
| C. 1.5D,1                                                    |
| D.                                                           |
| E.                                                           |
| F.                                                           |
| G.                                                           |
| H.                                                           |
| I.                                                           |
| J.                                                           |
| K.                                                           |
| L.                                                           |
| M.                                                           |
| N.                                                           |
| O.                                                           |
|The only available chalks for item 4.1_ are: 1, 4.            |
|Enter the chalk number to which you wish to move:             |
|                                                              |
|                                                              |
+--------------------------------------------------------------+
```

Figure 10.   Compatible Chalk Listing for Moving an Item

Display. By pressing "D" or "2", the matrix will be
displayed again. To return to the chalk listings, press any
key.

Print. To print the chalk listing, press the "P" or
"3" key. This option prints the current screen to the
printer connected to the computer.

Rerun. To return to the data entry screen and run the
program again, press the "R" or "4" key.

Exit. By pressing the "X" or "5" key, HAZARD will exit
the program and return to the DOS prompt (Figure 8).

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```
        Chalk Listings Based on Compatibility   (Element,Priority)

        1         2         3         4         5         6         7         8
     Cls/Pri   Cls/Pri   Cls/Pri   Cls/Pri   Cls/Pri   Cls/Pri   Cls/Pri   Cls/Pri
    _____

A. 8.8_,2    7.8_,1    1.1B,1
B. 4.1_,2
C. 1.5D,1
D.
E.
F.
G.
H.
I.
J.
K.
L.
M.
N.
O.
The chalk you selected is not compatible with the item you identified.
Do you wish to move 4.1_ to chalk 2 on a waiver (Y/N)?
```

Figure 11.   Moving an Item Under Waiver Authority

Appendix D: Software Questionnaire

The following questions pertain to the hazardous cargo compatibility determination program, HAZARD.

1. How long have you been involved in loadplanning operations?

     a.   Less than 1 year
     b.   1-3 years
     c.   3-5 years
     d.   More than 5 years

2. Are you aware of the pending changes to AFR 71-4?

     a.   Yes
     b.   No

3. Are you aware of the new international standards for classifying hazardous items?

     a.   Yes
     b.   No

4. How difficult is the use of the compatibility tables and associated notes in AFR 71-4 for determining compatibility?

     a.   Extremely difficult
     b.   Somewhat difficult
     c.   Neither difficult nor easy
     d.   Somewhat easy
     e.   Very easy

5. Would the software you reviewed enhance the efficiency of the loadplanning operation?

     a.   Yes
     b.   Unsure
     c.   No

6. Would the software help the novice as well as the experienced user?

     a.   Yes
     b.   Unsure
     c.   No

7. Could this software be used to as a training aid for new loadplanners?

   a. Yes
   b. No

8. Would using this software speed up the loadplanning process?

   a. Yes
   b. Unsure
   c. No

9. How did you find the ease of use of this software?

   a. Extremely easy to use
   b. Fairly easy to use
   c. Neither easy nor hard
   d. Fairly hard to use
   e. Extremely hard to use

10. What enhancements or changes would you like to see to this software?

11. Do you feel this would be a suitable addition to the present automated loadplanning systems currently available, i.e. CALM, ADAM III?
   a. Yes
   b. No

Comments:

Name and phone number (optional)

_____

_____

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13. ABSTRACT (Maximum 200 words) This research demonstrates the application of expert system technology to automate the aircraft load selection process performed when transporting hazardous cargo. The resulting computer program is an expert system named HAZARD. This system incorporates the regulations governing hazardous cargo compatibility with the heuristics used by experts in load-planning operations. The impetus to develop such a system is the January 1993 conversion of regulation guidelines for hazardous cargo classification and management in Air Force Regulation 71-4, to a universal international standard. The Cargo Operations Division of Headquarters Air Mobility Command at Scott AFB, was concerned that this change in procedures and nomenclature may cause confusion to loadplanners. Therefore, it is the intention of this research to reduce the impact of this change to regulations through the development of an automated computer product designed for both the experienced and novice loadplanners. The use of this system will improve the accuracy and timeliness of the hazardous cargo compatibility determination process.

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